

DTIC FILE COPY

4

AD

AD-E401 828

TECHNICAL REPORT ARAED-1R-88011

**A HOLISTIC APPROACH DIRECTED TOWARD CONTROLLING
THE INBORE DEFLAGRATION HAZARD OF
COMPOSITION B, A CAST EXPLOSIVE**

AD-A196 635

R.W. VELICKY
H.W. VOIGT
S. NICOLAIDES

DTIC
ELECTE
JUL 25 1988
S of H D

AUGUST 1988



U.S. ARMY
ARMAMENT MUNITIONS
& CHEMICAL COMMAND
ARMAMENT RDE CENTER

U. S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

ARMAMENT ENGINEERING DIRECTORATE

PICATINNY ARSENAL, NEW JERSEY

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

33 02 9

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

The citation in this report of the names of commercial firms or commercially available products or services does not constitute official endorsement by or approval of the U.S. Government.

Destroy this report when no longer needed by any method that will prevent disclosure of contents or reconstruction of the document. Do not return to the originator.

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER Technical Report ARAED-TR-88011			5. MONITORING ORGANIZATION REPORT NUMBER		
6a. NAME OF PERFORMING ORGANIZATION ARDEC, AED		6b. OFFICE SYMBOL SMCAR-AEE	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (CITY, STATE, AND ZIP CODE) Energetics and Warheads Div Picatinny Arsenal, NJ 07806-5000			7b. ADDRESS (CITY, STATE, AND ZIP CODE)		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION ARDEC, IMD STINFO Br		8b. OFFICE SYMBOL SMCAR-IMI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (CITY, STATE, AND ZIP CODE) Picatinny Arsenal, NJ 07806-5000			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO. WORK UNIT ACCESSION NO.
11. TITLE (INCLUDE SECURITY CLASSIFICATION) A HOLISTIC APPROACH DIRECTED TOWARD CONTROLLING THE INBORE DEFLAGRATION HAZARD OF COMPOSITION B, A CAST EXPLOSIVE					
12. PERSONAL AUTHOR(S) R. W. Velicky, H. W. Voigt, and S. Nicolaides					
13a. TYPE OF REPORT		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (YEAR, MONTH, DAY) August 1988	
				15. PAGE COUNT 57	
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)		
FIELD	GROUP	SUB-OR-SUP	Explosive Composition B, TNT, Cast explosives, Hazard; Setback, Premature, Inbores explosion, Deflagration, DDT, Ignition, Thermal sensitivity, Combustion, Detonation, Sympathetic detonation, Shock sensitivity, Exudation, Pressure casting. (JET)		
19. ABSTRACT (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)					
<p>The castable explosive composition B can no longer be used in some artillery munitions of the U.S. Armed Forces because it is vulnerable to inbores thermal explosions. Such accidents are believed to result from a confluence of events and explosive properties that bring together two or more low probability events that lie within an ordered sequence. The holistic approach of this study requires that an improvement be made in each of four steps in this sequence so that a contribution would be made toward reducing the probability of an incident at each of these steps. Success in this endeavor would cause a rare event to become increasingly more rare at an exponential rate proportional to the degree of improvements made.</p> <p>This work shows that an improvement can be made in each of the contributory factors in the train of events that lead to an inbores premature accident. The successes achieved are intended to be viewed as a feasibility study, providing some guidelines and direction through which these effects may be optimized.</p>					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT			21. ABSTRACT SECURITY CLASSIFICATION		
<input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL I. HAZNEDARI			22b. TELEPHONE (INCLUDE AREA CODE) 201-724-3316		22c. OFFICE SYMBOL SMCAR-IMI-I

CONTENTS

	Page
Introduction	1
Cast Loading Procedure	2
Background (Pressure Casting)	2
Procedure and Results (Pressure Casting)	2
Results and Conclusions (Pressure Casting)	3
Experimental Formulations	4
Mechanical Properties	4
Procedure and Results (Uniaxial Compression)	4
Results and Conclusions (Uniaxial Compression)	4
Recommendations (Uniaxial Compression)	4
Thermal Ignitability	5
Background	5
Procedure and Results	5
Conclusions and Recommendations	6
Deflagration	6
Background	6
Procedure and Results	7
Results and Conclusions	7
Recommendations	8
Shock Sensitivity	8
Procedure and Results	8
Results and Conclusions	9
Exudation	10
Background	10
Procedure and Results	10
Results and Conclusions	10



Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

CONTENTS (cont)

	Page
Conclusions	11
References	45
Distribution List	47

TABLES

1	Sample formulations	13
2	50% response to pressure and energy	14
3	Relative ignitability equations	15
4	Slapper stimulated shock sensitivity	15
5	Relative performance at 9,000 volts	16
6	Analog of shock pressure (volts) versus output (g)	17

FIGURES

	Page
1 Atmospheric (dots) versus pressure cast comp B	19
2 Atmospheric versus pressure cast comp B	20
3a 1% polysulfone coated on RDX (2)	21
3b 2% polysulfone coated on RDX (3)	22
3c 3% polysulfone coated on RDX (4)	23
3d 1% PS on RDX and 0.12% HNS in TNT (5)	24
3e 1% PS on RDX and 0.5% PCP in TNT (6)	25
3f 1% PS on RDX and 0.12% HNS + 0.5% PCP in TNT (7)	26
4 Summary of mechanical property testing	27
5 Ignition test fixture	28
6 Effect of 1% and 3% RDX coatings	29
7 Effect of TNT modifiers with RDX coating	30
8 Effect of HNS without antiexudate (PCP)	31
9a 1% polysulfone coated on RDX (2)	32
9b 2% polysulfone coated on RDX (3)	33
9c 3% polysulfone coated on RDX (4)	34
9d 1% PS on RDX and 0.12% HNS in TNT (5)	35
9e 1% PS on RDX and 0.5% PCP in TNT (6)	36
9f 1% PS on RDX and 0.12% HNS + 0.5% PCP in TNT (7)	37
10 Summary of closed bomb burning test	38

FIGURES (cont)

	Page
11 Previously reported data	39
12 Summary of slapper stimulated shock sensitivity test	40
13 Summary of slapper stimulated explosive performance test	41
14 Performance of modified comp B versus standard explosives	42
15 Summary of exudation test	43

INTRODUCTION

The fundamental cause of inbore explosions is related to the interaction of an occasional casting flaw with the brittleness and structural weakness of a composition B casting. The flaw, a concentration of stress at a discontinuity, is the focus of catastrophic structural failure in response to setback stresses at launch. This creates a finite localized hot-spot which can initiate burning in the thermally sensitive explosive (ref 1). The timing of these events in relation to the reaction rate of the explosive then allows the rupture pressure of the projectile to be reached before it can exit the gun barrel.

The probability of an accident occurring is rare, suggesting that the prerequisites for the hazard are borderline. An appropriate correction or response at any of four steps (flaws, mechanical properties, ignitability, and reaction rate) would provide an interruption that will prevent an inbore explosion. The premise of this work is that a small improvement at each step would reduce the probability of an incident progressing through the sequence of events that lead to an accident. This would cause a rare event to become increasingly more rare at an exponential rate proportional to the degree of improvements made; the objective being to make the potential for an inbore explosion a statistically improbable occurrence.

The desired improvements appear to be achievable. There are suggestions that by combining vacuum degassing (ref 2) of the explosive melt with pressure casting (ref 3) in the loaded item virtually flaw-free castings could be achieved. The explosive's resistance to fracture can be improved with additives in the TNT melt. Work performed in Australia (ref 4) shows that a small quantity of hexanitrostilbene (HNS) can increase the toughness of TNT by a factor of four. A similar result should be obtained in composition B where TNT provides the form and structure of the cast explosive by functioning as an energetic binder for crystalline RDX.

RDX is the more thermally sensitive of the two explosives in composition B. Tests indicate that protecting each crystal with a thin coating inhibits ignition, thereby increasing the threshold of pressure and energy required to ignite the explosive in a projectile launch situation (ref 5). Moreover, closed bomb tests show that coating the RDX crystals with almost any compatible polymeric protectant significantly slows the reaction rate of composition B during its early stages of combustion (ref 6).

Each of the specific goals that have been outlined appear to be attainable, but for optimum effectiveness all the desirable properties must be combined within one formulation without developing serious negative tradeoffs. A group of formulations have been selected to address various aspects of the problem. They were tested for effects on the inbore hazard, shock sensitivity, and exudation.

CAST LOADING PROCEDURE

Background (Pressure Casting)

Casting techniques and procedures also influence the response of explosives to stimuli and in this regard an attempt was made to verify results reported in Australia (ref 3). Using the closed bomb technique, it was shown that the deflagration of composition B could be moderated, during the early stages of combustion, by allowing the explosive-melt to solidify under positive air pressure (pressure casting). This is an important indication that the cast quality of the material had been improved by the procedure.

Procedure and Results (Pressure Casting)

A batch of standard composition B was melted and poured into six 2.540 cm diameter split molds. Three of the molds were in a pressurizable container. Prior to solidification the container was closed and pressurized with air at 50 psi. Specimens of atmospheric and pressure cast materials were prepared for mechanical property and closed bomb testing. The densities were 1.680 ± 0.0010 and 1.697 ± 0.0015 g/cc, respectively.

For mechanical testing the specimens were machined into cylinders 1.270 cm in diameter by 2.540 cm long. They were tested in compression using an Instron universal tester at 18°C and a crosshead speed of 0.127 cm/min. The results are summarized in figure 1 (dotted lines represent atmospheric cast composition B). The area under the stress versus strain curve is the toughness of the formulation and represents the energy required to fracture it. The area under the curve was used as a basis for comparing the mechanical stabilities of the several formulations.

Closed bomb testing is used to provide an indication of the relative reaction rate (deflagration) of the explosives formulations. For this test cylindrical specimens 2.540 cm in diameter and approximately 4.5 cm long were used. The length of each specimen was adjusted to provide a constant weight of 37.77 grams. The samples were burned in a 178 cc closed bomb instrumented to measure the pressure developed with respect to time. A differentiation of these data plotted with respect to pressure is shown in figure 2. The pressure reflects the force per unit area produced by the evolving gases in relation to the rate at which they are being generated (dp/dt). The area under the curve combines all the factors that are responsible for the explosives reaction rate and is representative of deflagration of the formulation with respect to conditions defined by the particular test (vessel volume, geometry, mass, etc.) (ref 6, 7, 8).

Results and Conclusions (Pressure Casting)

Pressure casting at 50 psi does not improve the compressive toughness of standard composition B; however, a significant change is observed in the effect the pressure casting has on the explosive's burning properties. The closed bomb burning test of composition B cast in an atmosphere of 50 psi air pressure showed a 50% reduction in the deflagration rate.

Burning is essentially a surface related phenomenon. The rapid deflagration of composition B is due primarily to the rate at which RDX crystals are released from the TNT to become exposed for burning. Microvoids (porosity) locked within the cast would influence this rate of surface area generation and contribute to the catastrophic deflagration rate of composition B. It is presumed that the application of pressure during solidification compresses these microvoids and thereby curtails internal surface areas and ignition routes that influence deflagration. The slightly higher density of the pressure-cast composition B gives credence to the contention that the pore volume is reduced by the 50 psi pressure. It follows that a procedure which can control porosity may also beneficially control the number and severity of potential casting flaws.

EXPERIMENTAL FORMULATIONS

Earlier work (ref 6) has shown that precoating the RDX in composition B with a protectant moderates deflagration. This was achieved with polysulfone, plasticized polycarbonate, plasticized cellulose propionate, and even with the standard wax additive used in regular composition B. Polysulfone (PS), an aromatic heat resistant polymer, was selected for this work because of its potential to improve the explosive's resistance to mechanical breakup. It is believed that, (a) a small portion of the polysulfone may bleed into the TNT to produce seed crystals that could provide the basis for increasing the toughness of the cast, and (b) that the coating may enhance the wetting between the RDX crystals and the TNT matrix to soften grain boundaries. HNS is included because it improves the quality of TNT (ref 4).

Both TNT and composition B (40% TNT) exude when exposed to high temperature storage. Impurities in TNT, high temperature, and confinement combine to cause low-melting eutectics to migrate through the TNT, thus producing a potential hazard situation. Therefore, an additive designed to control exudation is also included. The antiexudate is a 50/50 mixture of cellulose propionate and epoxy plasticizers (PCP).

All the formulations were based on a 60/40 mixture of RDX/TNT, with the percentage modifier added. For the various formulations of this study, polysulfone was precoated on RDX. HNS and the antiexudate are TNT modifiers dissolved in the melt (0.12% and 0.5%, respectively). Complete descriptions of procedures and source

materials can be found in reference 6. The general formulations, with the identification numbers, used in this study are listed in table 1. These formulations were subjected to tests for: mechanical properties, thermal ignitability, deflagration, shock sensitivity, explosive output, and exudation

MECHANICAL PROPERTIES

Procedure and Results (Uniaxial Compression)

The same procedures used to evaluate the toughness of pressure cast composition B were used for the seven RDX/TNT (60/40) based formulations. The stress versus strain curves for each of the six experimental formulations are shown in figures 3a - 3f and compared with the results obtained for standard composition B (dotted lines). The toughness (area under the curve) is measured for each formulation and is included in the graphical comparison. The average toughness of composition B is assigned a value of 100% and a relative comparison is made. A summary of all the data is presented in the form of a bar graph (fig. 4)

Results and Conclusions (Uniaxial Compression)

The toughness of composition B can be improved. All the experimental formulations have, in uniaxial compression, increased their ability to resist breakup or fracture over that of standard composition B by a factor of three. In loaded projectiles this degree of improvement can be expected in three dimensions. It appears that the polysulfone coating is responsible for the improvement. The ability of HNS to improve cast quality was not confirmed by this work. Presumably the polysulfone coating masked its effect.

The degree of improvement achieved would be sufficient to reduce the probability of potential incore explosions. Although this probability would be reduced by a material that is three times tougher, the potential for an accident is still present if catastrophic brittle failure were possible. More heat energy would be generated during the collapse of proportionately stronger materials. Therefore, it is also important to desensitize the explosive to ignition and slow down deflagration.

Recommendations (Uniaxial Compression)

It is believed that the improvement in the toughness of composition B was achieved by some of the polysulfone coating interacting with the TNT to create a fine, random, interlocking crystal structure for the binder similar to the effect of HNS with TNT. However, this is only an assumption. The mechanism should be investigated in detail by microscopist and material specialists in order to take full advantage of the phenomenon.

An alternate approach to prevent catastrophic brittle failure in composition B may be available. There is a family of additives, miscible with TNT, capable of imparting various degrees of malleability to the physical structure of Composition B (ref 9). Plasticization of Composition B would reduce the rapidity of the ignition energy satisfying mechanism, dissipating the mechanical energy created by collapse over broader areas and for much longer time periods, virtually eliminating the fundamental cause of inbore accident. A detailed study to determine which agent could impart the optimum plastic flow characteristics in TNT with the least amount of material should be pursued.

THERMAL IGNITABILITY

Background

Inbore ignitions in composition B are initiated by a finite quantity of localized heat energy generated by dynamic setback pressures induced by projectile propulsion. The test employed in this study (ref 10) evaluates the response of the experimental formulations to the parameters responsible for ignition under these conditions (pressure and energy).

Procedure and Results

A fixed quantity of electrical energy is discharged into a 1 ohm, 2.5 mil diameter, no. 479 platinum heater which is located in the center of a 3/4 gram sample housed in a fixture that permits pressurized loading of the specimen (fig. 5). The test is performed by discharging a fixed quantity of electrical energy into the sample and varying the static pressure load according to a 25 shot Bruceton up and down procedure. The explosive's 50% probability of an ignition response is obtained with respect to a specific combination of pressure and energy. This test is repeated at several energy levels providing data for straight lines which are used to determine the relative effectiveness of additives to desensitize RDX/TNT (60/40) against hotspot ignition.

A measurement of the energy delivered to the heater was obtained for each shot in the Bruceton series. The average, with its corresponding Bruceton derived 50%-fire pressure of initiation, is tabulated in table 2 for each explosive tested. The reciprocal of this pressure versus the energy input, produces a linear relationship that is used to rank the thermal sensitivity of the explosives. The coefficients for a straight line equation for these data are shown in table 3 together with the correlation of determination (r^2). Values of r^2 close to 1.00 indicate a very good fit to the data, providing an indication of the overall precision of the entire population tested.

With reference to standard composition B, these data are plotted in three ways to demonstrate several points. Precoating RDX in the formulations with polysulfone increases the pressure and energy required to stimulate an ignition (fig. 6). The reactive constituents of composition B are desensitized against thermal ignition in proportion to the quantity of material used to coat the RDX.

HNS and the antiexudate (PCP) are special purpose TNT modifiers added to the melt prior to casting. When these modifiers are combined in the formulation, they do not interfere with the ability of the polysulfone protective coating to inhibit ignition (fig. 7).

In figure 8, the ability of HNS to effect ignition is separated from that of the antiexudate and compared with the combined formulation. This shows that HNS in combination with a coated RDX enhances desensitization and that this desirable property is neutralized when the antiexudate is added to the mixture.

Conclusions and Recommendations

The major conclusion that can be drawn from these results is that composition B can be measurably desensitized against thermal ignition with small quantities of additives. The combination of pressure and energy required to stimulate an ignition is increased; therefore, it can be expected that the probability of an in-bore ignition would be reduced further at the third stage of the sequence leading to an in-bore explosion.

The thermal desensitization was achieved with the RDX precoated with a protectant and further enhanced with a modifier in the TNT melt. In this case the protective coating is polysulfone and the TNT modifier is HNS; however, it must be assumed that there are other materials that would function as well or better. Although the mechanism of desensitization is not well understood, it is believed that the polysulfone coating is chemically passive and it is merely its location and physical presence that cause it to function as a thermal barrier for RDX. It is possible that compounds which actively quench thermal reactions such as hydrated coolants (ref 2) or reaction scavenging ionic flame suppressants (ref 9) when strategically targeted may desensitize the explosive against hotspot ignition even more effectively.

DEFLAGRATION

Background

Utilization of the closed bomb techniques as applied generally to the burning of gun propellants provides insight into the burning behavior of composition B (ref 8). When ignited at atmospheric pressure composition B first burns upon its surface according to

standard linear regression laws. Its catastrophic deflagration begins when the combination of temperature and pressure in the reaction zone causes the release of individual particles of RDX from the TNT binder for surface burning. As burning progresses, the surface area of the RDX increases at a rate which accelerates as a function of pressure while each RDX particle regresses toward its geometrical center at a burning rate which also accelerates as a function of pressure. Simultaneously, the burning TNT is contributing its share to the developing pressure. These three accelerating mechanisms coalesce to cause catastrophic burning in composition B.

The standard 1% wax added to composition B moderates deflagration. During melt casting a portion of the wax (immiscible in TNT) coats the RDX crystals. This coating appears to inhibit the response of each RDX particle in the sequence of ignition and burning. This has the effect of slowing down the burning of the explosive. Based on this it was found that intentionally precoating the RDX with a polymeric protectant significantly improved this ability to control deflagration in composition B.

Procedure and Results

The closed bomb technique discussed under the pressure casting section was also used here, the exception being that the specimen weight, was based on a constant 37.40 grams of the reactive ingredients (RDX/TNT). A complete series of the seven formulations were tested on three consecutive days in order of their sample identification numbers. The deflagration related data, in the form of dp/dt versus pressure is plotted in figures 9a-9f. Each of the formulations is shown relative to standard composition B (dotted lines). The area under these curves are listed on the graphs. The area under the curve for regular composition B is assigned a value of 100% and a relative comparison based on this value is made for the experimental formulation. A summary of these data are represented in the form of a bar graph (fig. 10).

For the convenience of the reader a summary of some earlier reported data (ref 5) is repeated in figure 11. The same procedures were followed using a smaller specimen weight (32.00 grams).

Discussion of Results and Conclusions

The results reported here were not consistent with earlier reported work. The earlier work indicated that several RDX coatings (standard wax, polysulfone, polycarbonate, and cellulose propionate) moderated deflagration and that this enhancement was not seriously compromised by the addition of TNT modifiers (HNS and the antiexudate, PCP). In this work the 1% polysulfone coating achieved a 50% reduction in deflagration, but the addition of TNT modifiers, either separately or together, nullified the effect. Even more surprising is that increasing the quantity of what is thought to be a protective layer around the RDX appears to increase the rate of deflagration.

It is believed that both sets of data are correct and that it is in the preparation of the materials tested that the differences are found. The intention was to coat the RDX with a protectant that would totally envelop each particle and remain in place during the melt and casting procedure. Microscopic examinations of the cast material were ambiguous, and it has become doubtful that the coating was obtained to the degree expected. In spite of the contradictory data, it is still believed that protective coatings can inhibit deflagration in the presence of TNT modifiers (refs. 5, 6, 8). These results point up the need for procedures that achieve complete coverage and satisfactory bonding of the coating material to each RDX crystal.

The coatings for this work were applied to the RDX by wet chemistry techniques that resulted in conglomeration for the 2% and 3% formulations. These aggregates required mechanical processing that could expose bare RDX. Spray drying equipment is now becoming available which promises efficiently produced RDX coatings of superior quality. Preliminary test with inerts indicate that almost any desired coating thickness can be applied to powder surfaces and quality or coverage can be demonstrated with various dyes.

Recommendations

Slowing the reaction rate of composition B in the early stages of ignition and burning is extremely important to all deflagration hazard situations as well as to its in-bore explosion problem. This can be accomplished with a protective coating enveloping the RDX and also by minimizing porosity with pressure casting. The experimental protective coatings used thus far have been passive in that they appeared to function as simple thermal barriers to ignition and the subsequent propagation rate of ignition and burning into the explosive.

This encourages the concept of going to the next step and using active flame retardants such as hydrates (ref 2) or ionic flame suppressants (ref 9). These types of additives, targeted to quench reactions on demand, in combination with pressure casting may inhibit or delay initial ignitions and slow any potential combustions sufficiently to assure a down range (out-of-bore) explosion of the projectile in the event all preventive measures had failed.

SHOCK SENSITIVITY

Procedure and Results

The formulation modifications are aimed at controlling the hazards that arise from ignition and burning. It is equally important to know how these modifications affect shock sensitivity and performance (detonation). The exploding foil slapper technique was used to evaluate shock sensitivity (ref 11). A modification of that test equipment was used to provide an indication of relative output (ref 12).

The exploding foil shock sensitivity tester utilizes energy stored in a capacitor to propel a thin filmed flyer plate to impact an explosive specimen which is pressed at 35,000 psi within the confinement of a steel sample holder. The flyer plate, at a velocity proportional to the capacitor charge produces a precise increment of shock pressure in the explosive which stimulates related initiations and reactions. A linear relationship, over the range of the tests, allows the capacitor charging voltage to be used as an analog of the shock pressure. A 25-shot Bruceton up and down procedure is used to determine the 50% detonation response to an analog of shock pressure stimulus. A detonation is defined to begin when the explosive reaction causes the 0.144 inch i.d. of the steel sample holder to expand sufficiently to allow a 0.152-inch gage to pass freely through the hole. The results for the seven formulations tested are listed in table 4 and represented graphically in figure 12.

The explosive output test employs the above exploding foil slapper assembly to stimulate detonations. A measure of plastic deformation in the confining metal parts provides the means for evaluating output (ref 12). A typical detonation signature is produced in a steel witness. Its volume, a function of modeling clay weight, is used to evaluate explosive output. Seven tests per formulation were stimulated with a shock pressure analogous to a 9,000 volt charge on the capacitor. This value was arbitrarily selected in the belief that it would probably stimulate prompt detonation in the explosive. The weight of clay required to fill the dent produced by the reaction of each formulation is listed in table 5. Standard composition B is assigned a value of 100% and a relative output comparison is made for each experimental formulation. A graphical representation of these data is presented in figure 13.

The explosive sensitivity and output data plotted in figure 14 and listed in table 6 were obtained using a different approach. The experimental formulation with 1% polysulfone coated on the RDX (sample 2) was selected for comparison with three standard explosives (TNT, composition B, and RDX). Reactions in these explosives were stimulated with a spectrum of shock pressures analogous to capacitor charges of 6,000 to 12,000 volts, allowing progressive observation of the reaction from minimal initiation to the maximum detonation velocity intrinsically possible for the explosives in the 1/8-inch run distance of this test.

Results and Conclusions

The modifications made to compositions B, in general, increase its sensitivity to shock stimulus. Military explosives require sophisticated fuse train systems to initiate detonation. Outside of a malfunctioning fuse it is extremely difficult to accidentally create a shock stimulus that would detonate an explosive. Most accidents begin with hotspots, of various magnitudes, that initiate burning in the explosive. If sufficient confinement or material is present a transition from deflagration to detonation (DDT) can occur. If the concepts being developed in this work can be successfully combined,

then some of the factors controlling DDT can be moderated. The hazard cannot be eliminated, but the source of the ignition, confinement, or quantity of the explosive needs to be greater than the norm to result in the same severity of a DDT accident. A negative tradeoff, however, does rise in the event a DDT does occur and neighboring munitions would be more vulnerable to sympathetic detonation.

The work of Machacek et al (ref 9) indicates that the problem may be circumvented. TNT miscible additives which impart desirable plastic flow properties to composition B also desensitize the explosive to shock initiation.

EXUDATION

Background

Exudation is a process of deterioration that weakens the structure of composition B with the passage of time. Impurities, high temperature, and pressure combine to cause low melting eutectics to migrate through the TNT matrix. It is desirable to minimize this behavior.

Procedure and Results

The problem appears to be based on impurities created in TNT by its manufacturing process. Rather than strive for a purer TNT product the approach taken here is to interpose a barrier to the migration mechanism through the use of TNT additives. A 50/50 mixture of stabilizing plasticizers and cellulose propionate (PCP) comprises the antiexudate (0.5%) used in the TNT melt. The rationale for its use as well as techniques and test procedures are described in reference 3.

Briefly stated the exudation test simulates the confinement of an explosive within an artillery projectile. A length to diameter ratio of 6 (6 in. long x 1 in. dia.) in a 110-gram specimen approximates the geometry of a typical shell filler. The test fixture is subjected to a constant temperature (71°C) for a specified period of time (160 and 320 hr). The exudation that occurs is collected on special absorbent paper that envelops the explosive. The weight of exudate is reported as a percentage of the initial specimen. The limited quantity of material available for this study permitted only one test per formulation. Numerous tests of the PCP antiexudate system were successfully conducted previously (ref 13). The results are listed in table 7 and graphically shown in figure 15.

Results and Conclusions

With only one test per formulation no attempt is made to interrelate the effect of additives with respect to one another on exudation. However, the data dramatically indicate that under the conditions of an accelerated exudation test the antiexudate

formulation can virtually eliminate the problem. This conclusion, although based on only two tests with the additive is sufficiently promising to encourage intensive investigation in a problem area that is potentially unsafe.

CONCLUSIONS AND RECOMMENDATIONS

The principle objective of this feasibility study has been achieved. It has been demonstrated that an improvement can be made at each of four steps in the progression of events that lead to potential inbore explosions with composition B. The probability of an incident occurring would diminish exponentially with an improvement at each step. These steps involve correcting the prerequisites (flaws and brittle failure) and desensitization to the resulting thermal response (ignition and deflagration).

A flaw of sufficient magnitude is the trigger which starts the accident. The closed bomb burning test indicates that pressure casting would reduce the number and severity of these flaws. The existence of a flaw provides the focal point for hotspot ignition because of the brittleness and structural weakness of the casting. A sudden collapse of the structure in response to inertia creates the hotspot which can ignite the explosive. The ability of the explosive formulation to resist this collapse can be increased by a factor of three. This would have a favorable impact on the statistics of inbore explosions.

There is still concern, however, that a sufficiently serious flaw may, even with stringent controls and improved techniques, be accidentally introduced in to the casting. In stronger material, structural failure could develop increased quantities of potential energy that would almost certainly ignite the explosive. The work of Machacek (ref 9) suggests that taking the opposite approach of making the structure more pliable may be more fruitful. He indicates that virtually any degree of malleability can be imparted to composition B with TNT miscible additives. This approach has the potential on its own of providing a composition B formulation that is invulnerable to inbore explosions and should be seriously examined.

Even if inbore explosions could be totally prevented at the second step of the hazard train, the investigation of factors which moderate ignitability and reaction rate (third and fourth step) should be continued. These are the properties of an explosive that control deflagration-to-detonation (DDT) in any hazard situation as well as contributing to inbore explosions. There is a link between compositions B's ignitability and its subsequent reaction rate, whereby both properties have been successfully inhibited with thin passive RDX coatings. This suggests that thin coatings of active suppressants that work at inhibiting reactions through cooling or ionic exchange on demand, may be better at mitigating the hazards of ignition threats and deflagration.

Shock initiation and hotspot ignition are responses to different mechanisms. The formulation modifications intended to improve the explosives thermal behavior increased its sensitivity to shock stimulus. This is a negative tradeoff that can increase the explosive's vulnerability to sympathetic detonation and appears to be related to improved mechanical properties. The work of Machacek again provides the opportunity to avoid this problem. TNT miscible additives, which impart beneficial plastic flow properties to the physical structure of composition B also desensitize the explosive to shock sensitivity.

The problem of exudation is a side issue to this work. It is conceivable, if not probable, that serious flaws might be developed through the migratory flow mechanism of exudation and in some way contribute to inbore explosions. Exudation in composition B can be controlled, and as work progresses with new variations of composition B the problem of exudation should be examined.

Table 1. Sample formulations*

1. 1% wax in TNT (standard composition B)
2. 1% polysulfone precoated on RDX
3. 2% polysulfone precoated on RDX
4. 3% polysulfone precoated on RDX
5. 1% polysulfone on RDX and 0.12% HNS in TNT
6. 1% polysulfone on RDX and 0.5% PCP in TNT
7. 1% PS on RDX and 0.12% HNS + 0.5% PCP in TNT

*All formulations based on RDX/TNT (60/40).

Table 2. 50% response to pressure and energy

Sample no.	Capacitor charge (volts)	Energy (joules)	Threshold Pressure (MPa)	Reciprocal Pressure (1/MPa)
1	90	0.0288 ± 0.0010	126.6 ± 17.8	0.00790
	110	0.0517 ± 0.0010	96.6 ± 6.3	0.01036
	130	0.0690 ± 0.0010	83.0 ± 5.3	0.01204
	150	0.0950 ± 0.0014	71.0 ± 8.6	0.01408
3	90	0.0329 ± 0.0005	133.4 ± 15.6	0.00750
	110	0.0506 ± 0.0007	115.0 ± 6.8	0.00869
	130	0.0678 ± 0.0034	95.1 ± 7.0	0.01052
	150	0.0953 ± 0.0014	79.3 ± 13.3	0.01261
4	90	0.0334 ± 0.0009	141.6 ± 15.1	0.00706
	110	0.0512 ± 0.0009	117.6 ± 7.0	0.00850
	130	0.0738 ± 0.0010	105.8 ± 5.8	0.00945
	150	0.0976 ± 0.0016	86.6 ± 5.2	0.01154
5	90	0.0321 ± 0.0006	147.1 ± 2.0	0.00684
	110	0.0483 ± 0.0012	130.2 ± 10.3	0.00768
	130	0.0681 ± 0.0008	106.6 ± 3.3	0.00939
	150	0.1000 ± 0.0014	87.2 ± 5.3	0.01146
6	90	0.0335 ± 0.0008	135.5 ± 2.8	0.00738
	110	0.0514 ± 0.0008	115.1 ± 10.1	0.00869
	130	0.0729 ± 0.0011	94.7 ± 10.2	0.01056
	150			
7	90	0.0343 ± 0.0007	134.2 ± 7.8	0.00745
	110	0.0462 ± 0.0010	118.4 ± 14.3	0.00845
	130	0.0672 ± 0.0015	100.5 ± 12.3	0.00995
	150	0.0921 ± 0.0019	81.6 ± 7.8	0.01225

Table 3. Relative ignitability equations

Sample	Slope	Intercept	r^2
1. Composition B	0.0934	0.00539	0.994
3. 1% PS coating only	0.0837	0.00467	0.994
4. 3% PS coating only	0.0669	0.00486	0.982
5. 1% PS coat and HNS	0.0698	0.00453	0.993
6. 1% PS coat and PCP	0.0809	0.00462	0.998
7. 1% PS coat and HNS + PCP	0.0833	0.00455	0.996

Table 4. Slapper stimulated shock sensitivity

Sample	Density g/cm^3	Shock sensitivity (volts)
1. Composition B	1.65 ± 0.004	5215 ± 166
2. 1% PS coating only	1.66 ± 0.004	4801 ± 185
3. 2% PS coating only	1.65 ± 0.002	4766 ± 355
4. 3% PS coating only	1.65 ± 0.005	4978 ± 395
5. 1% PS coat and HNS	1.67 ± 0.006	4928 ± 205
6. 1% PS coat and PCP	1.65 ± 0.008	5131 ± 213
7. 1% PS coat and HNS + PCP	1.65 ± 0.009	5159 ± 121

Table 5. Relative performance at 9,000 volts

<u>Sample</u>	<u>Dent*</u> <u>(g)</u>	<u>Relative Output</u>
1. Composition B	0.0342 \pm 0.0017	100%
2. 1% PS coating only	0.0369 \pm 0.0014	108%
3. 2% PS coating only	0.0356 \pm 0.0034	104%
4. 3% PS coating only	0.0355 \pm 0.0025	104%
5. 1% PS coat and HNS	0.0361 \pm 0.0027	106%
6. 1% PS coat and PCP	0.0368 \pm 0.0010	108%
7. 1% PS coat and HNS + PCP	0.0365 \pm 0.0021	107%

*Grams of clay needed to fill dent volume.

Table 6. Analog of shock pressure (volts) versus output (g)

Shock pressure (volts)	TNT (g)	Comp B (g)	1% coat (g)	RDX (g)
6,000	0.0	0.0	0.0177	0.0430
6,500	0.0	0.0	0.0308	—
7,000	0.0019	0.0032	0.0364	0.0468
7,500	0.0146	0.0117	0.0348	—
8,000	0.0190	—	0.0403	0.0470
8,000	0.0243	0.0266	0.0355	0.0480
9,000	0.0251	0.0328	0.0372	0.0475
9,500	0.0249	0.0386	0.0402	0.0479
10,000	0.0252	0.0386	0.0395	0.0478
10,500	0.0263	0.0386	0.0404	0.0474
11,000	0.0256	0.0361*	0.0404	0.0474
11,500	0.0256	0.0395	0.0383*	0.0485
12,000	—	0.0387	0.0416	0.0491

*Omitted from plot.

0.0384 ±	0.0401 ±
0.0011	0.0011
(100%)	(104%)

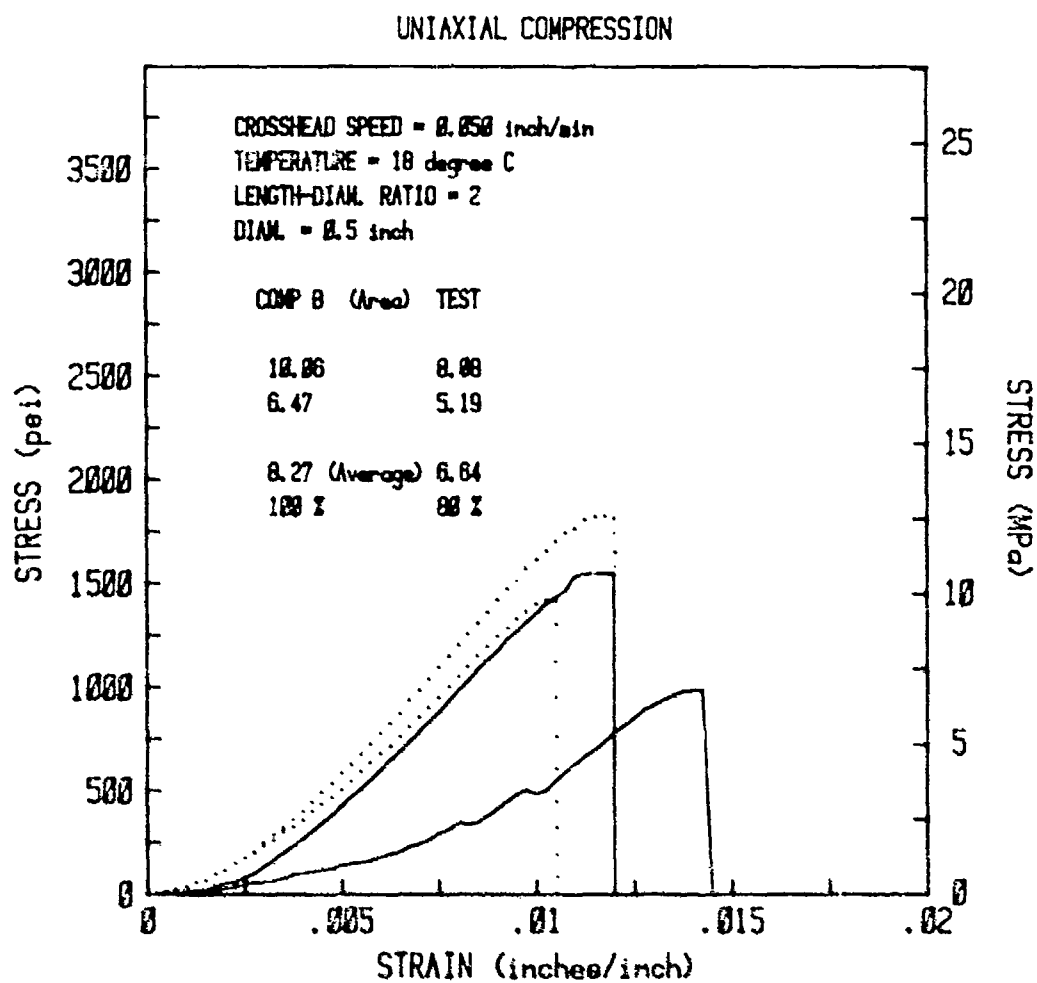


Figure 1. Atmospheric (dots) versus pressure cast comp B

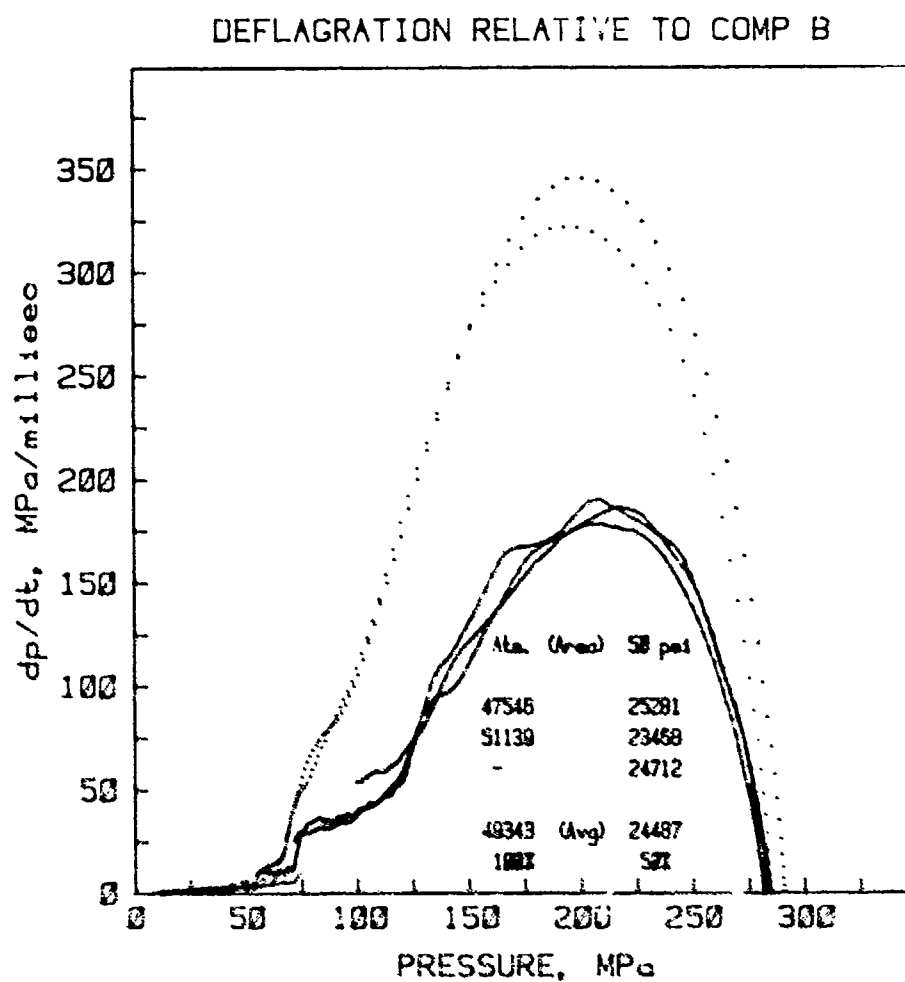


Figure 2. Atmospheric versus pressure cast comp B

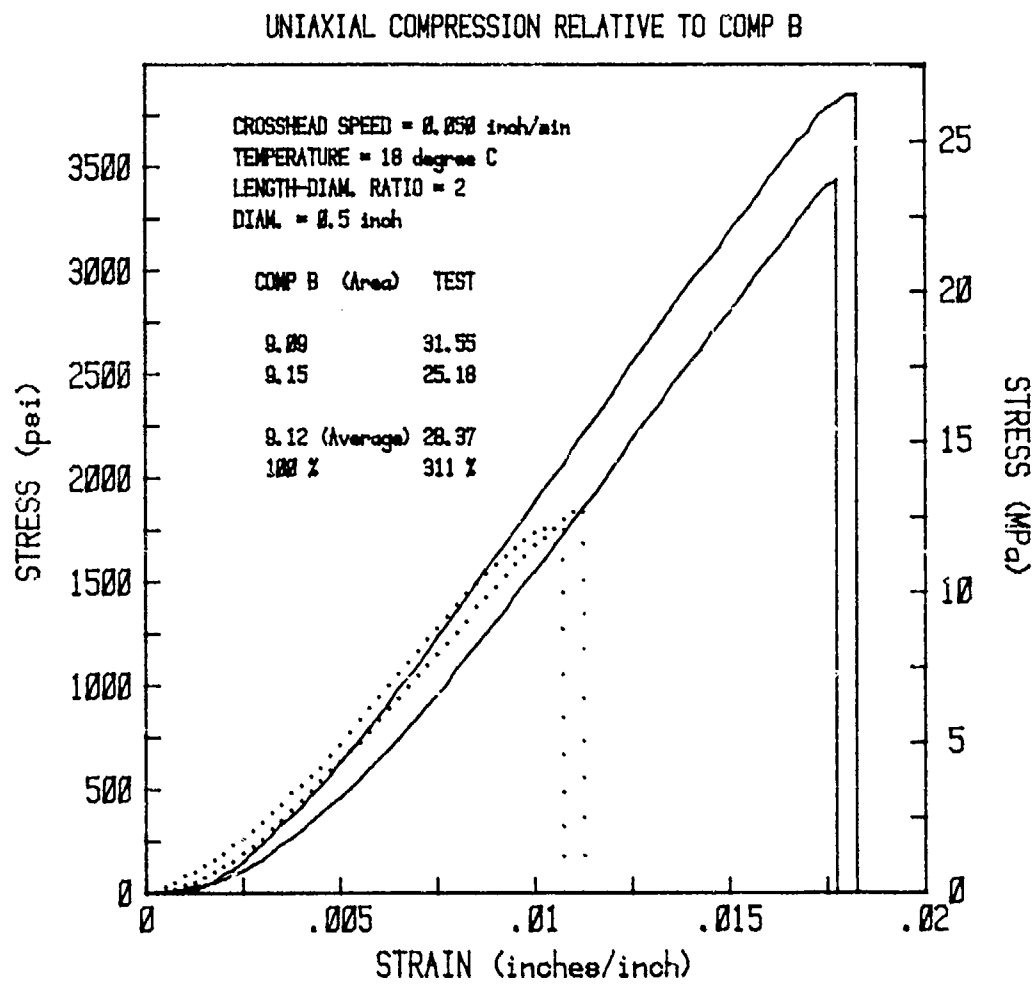


Figure 3a. 1% polysulfone coated on RDX (2)

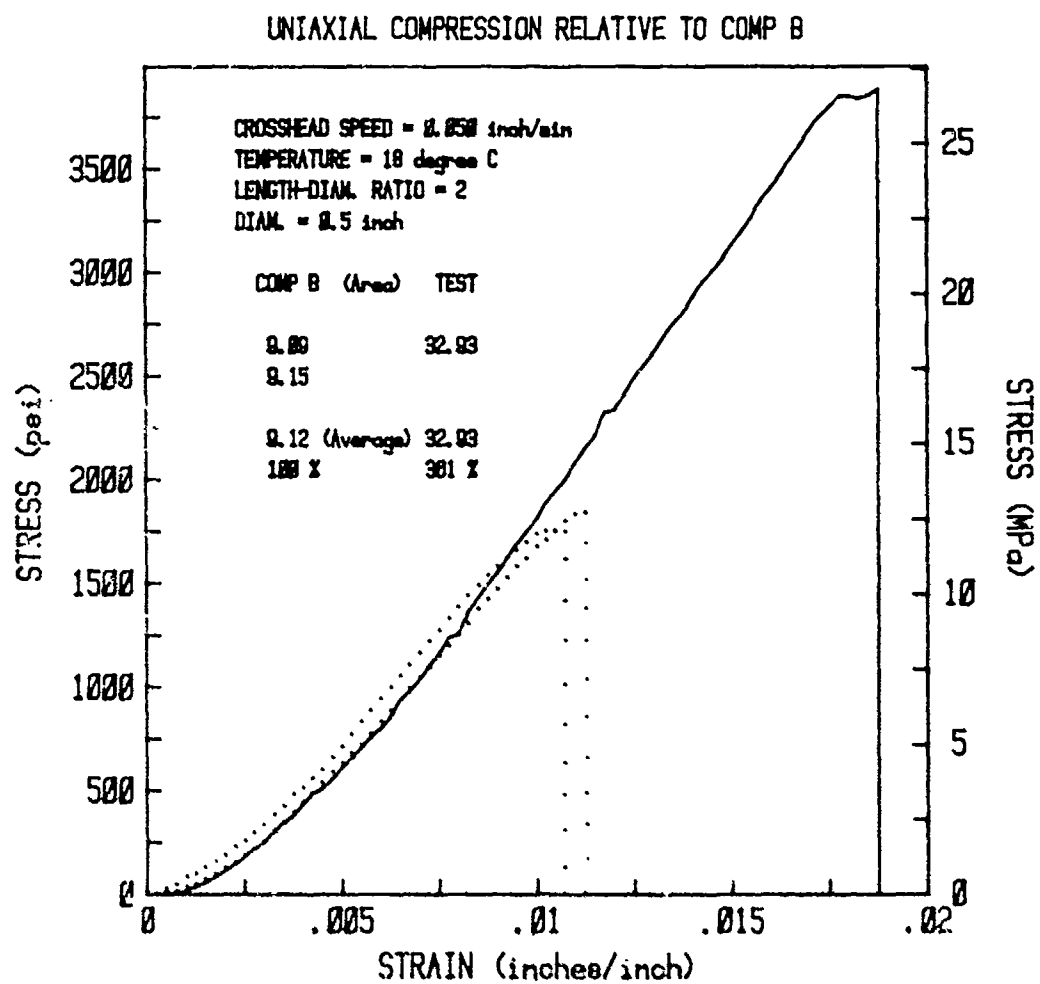


Figure 3b. 2% polysulfone coated on RDX (3)

UNIAXIAL COMPRESSION RELATIVE TO COMP B

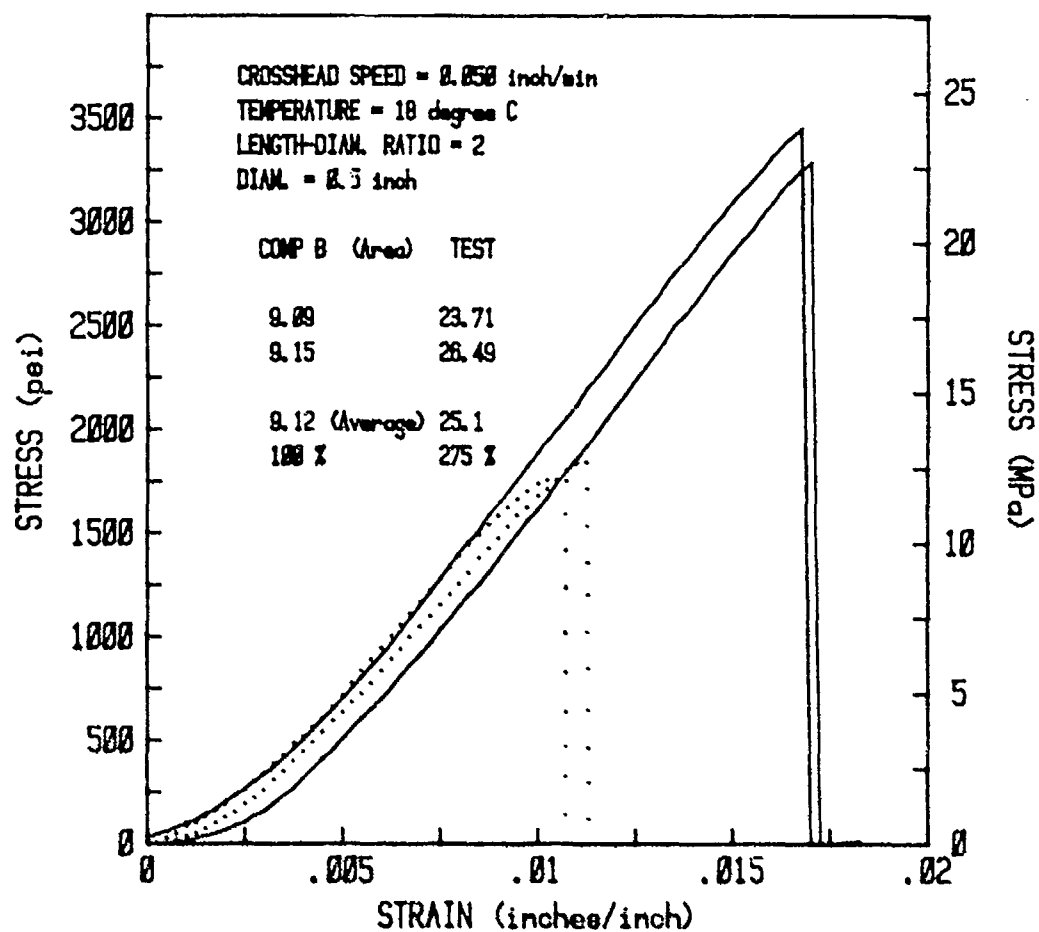


Figure 3c. 3% polysulfone coated on RDX (4)

UNIAXIAL COMPRESSION RELATIVE TO COMP B

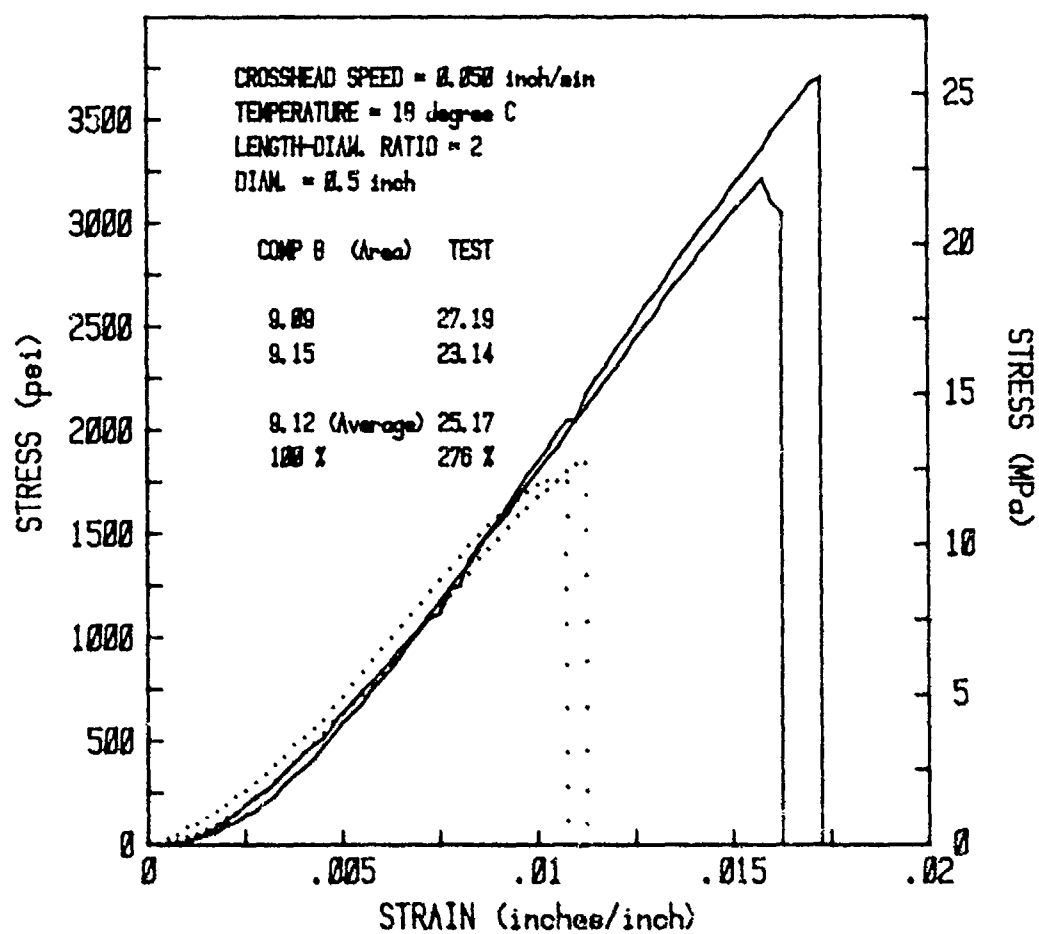


Figure 3d. 1% PS on RDX and 0.12% HNS in TNT (5)

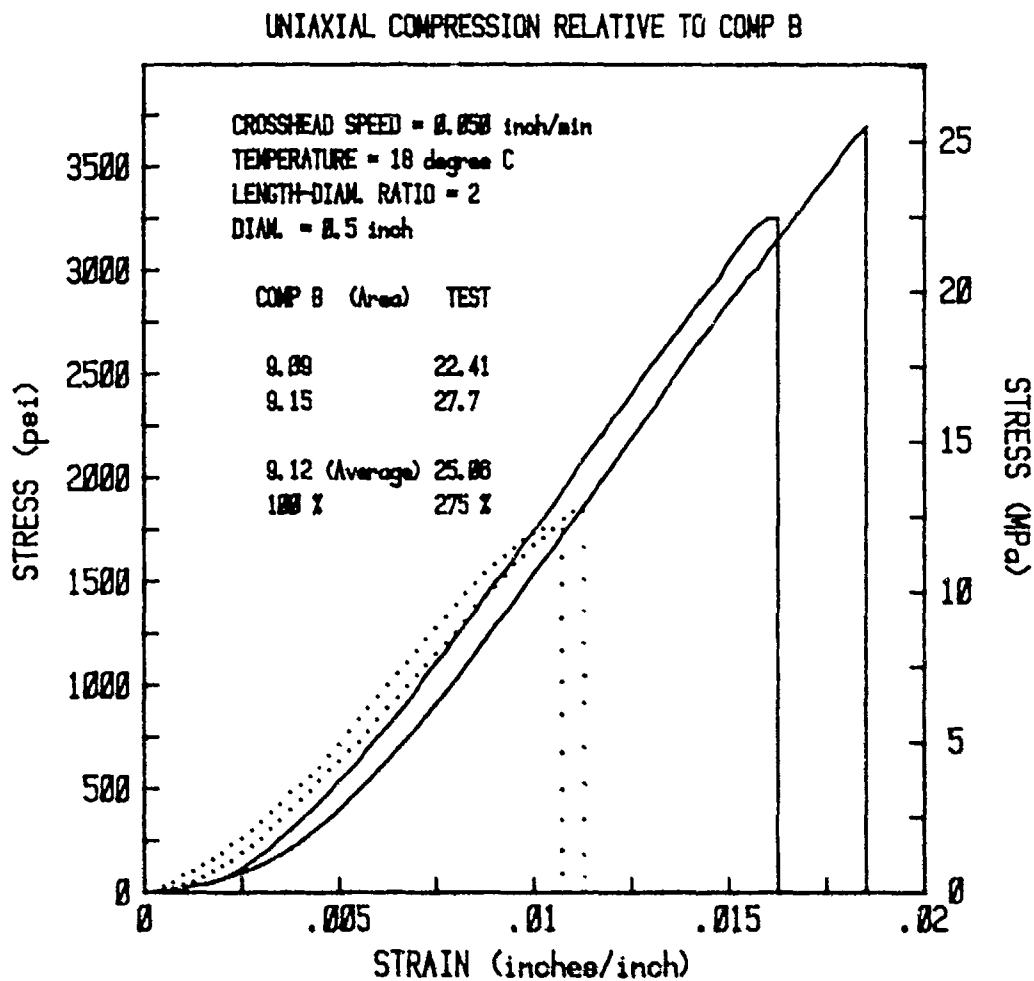


Figure 3e. 1% PS on RDX and 0.5% PCP in TNT (6)

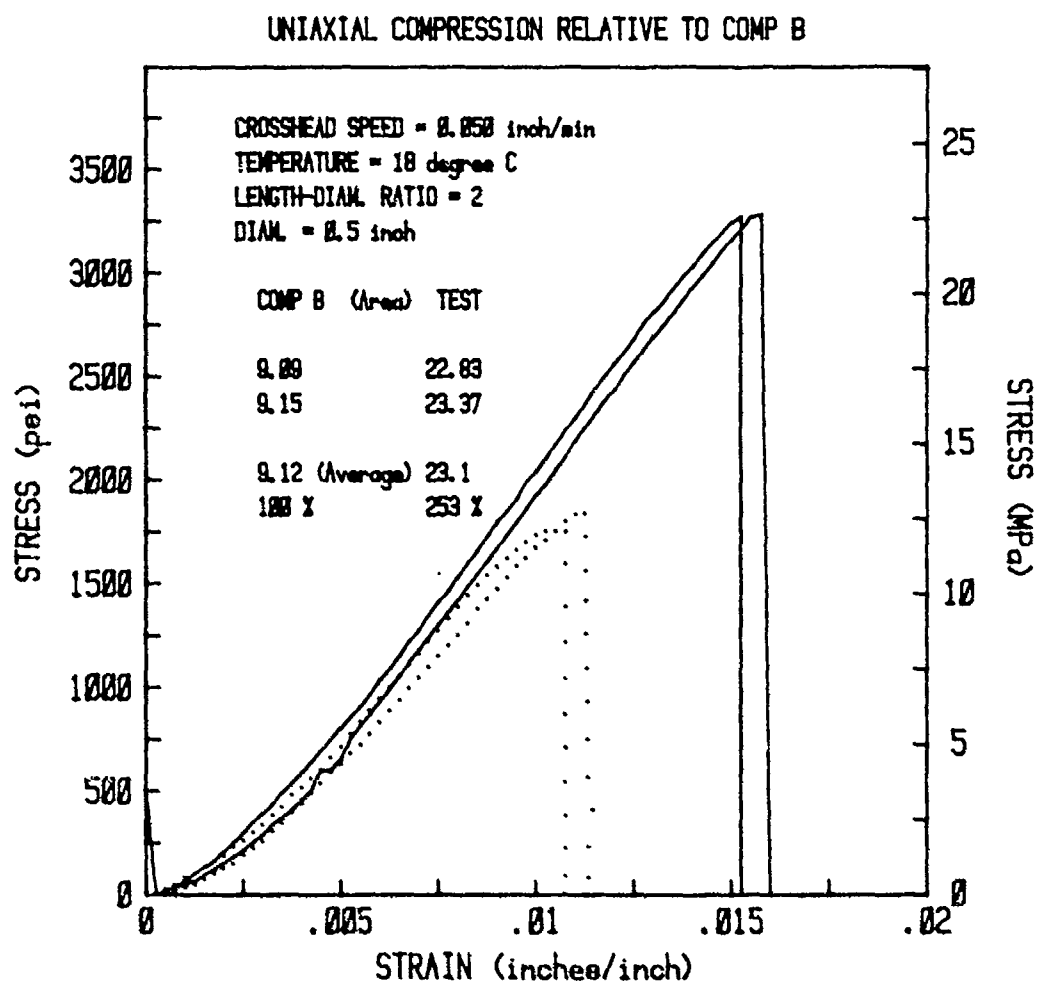


Figure 3f. 1% PS on RDX and 0.12% HNS + 0.5% PCP in TNT (7)

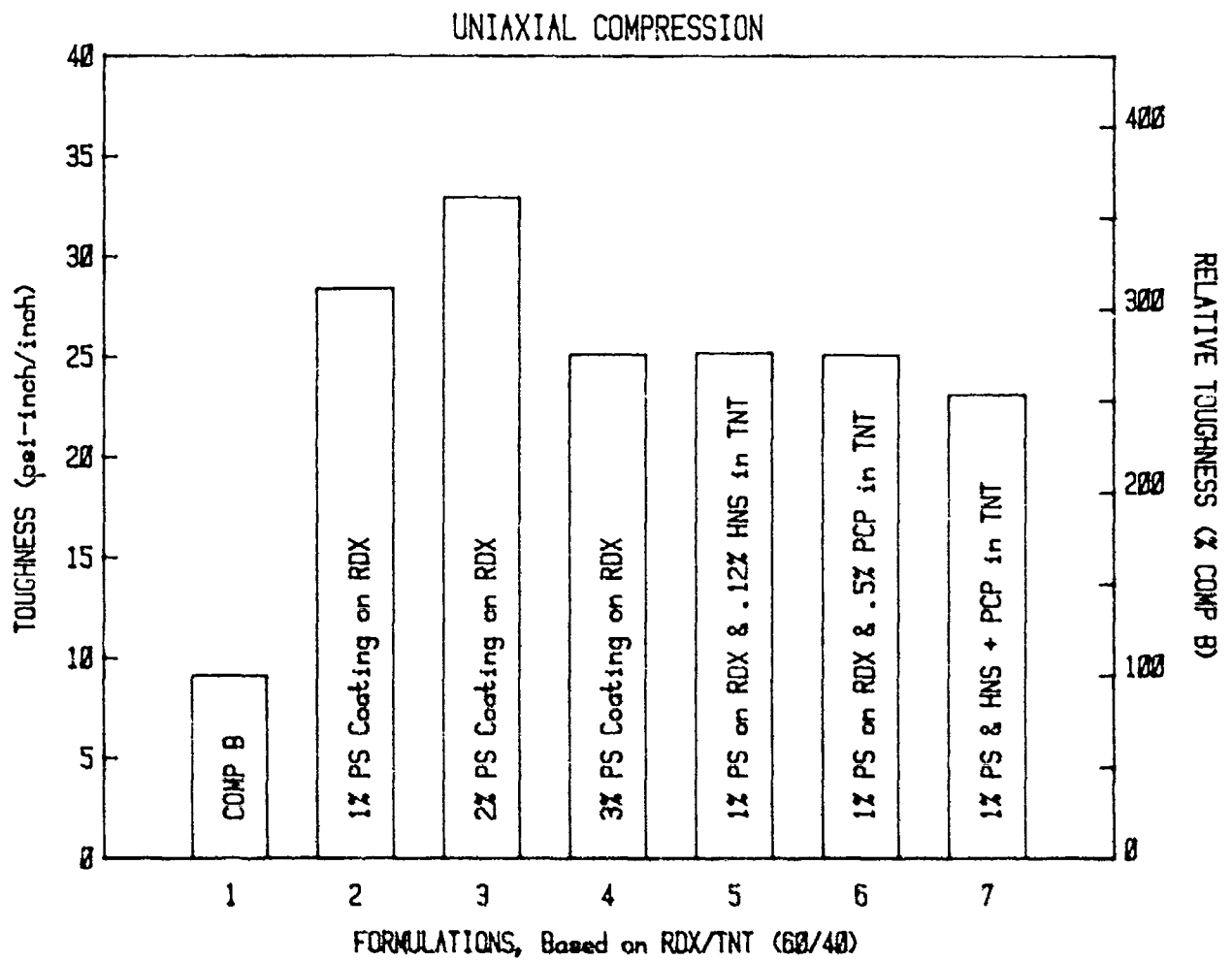


Figure 4. Summary of mechanical property testing

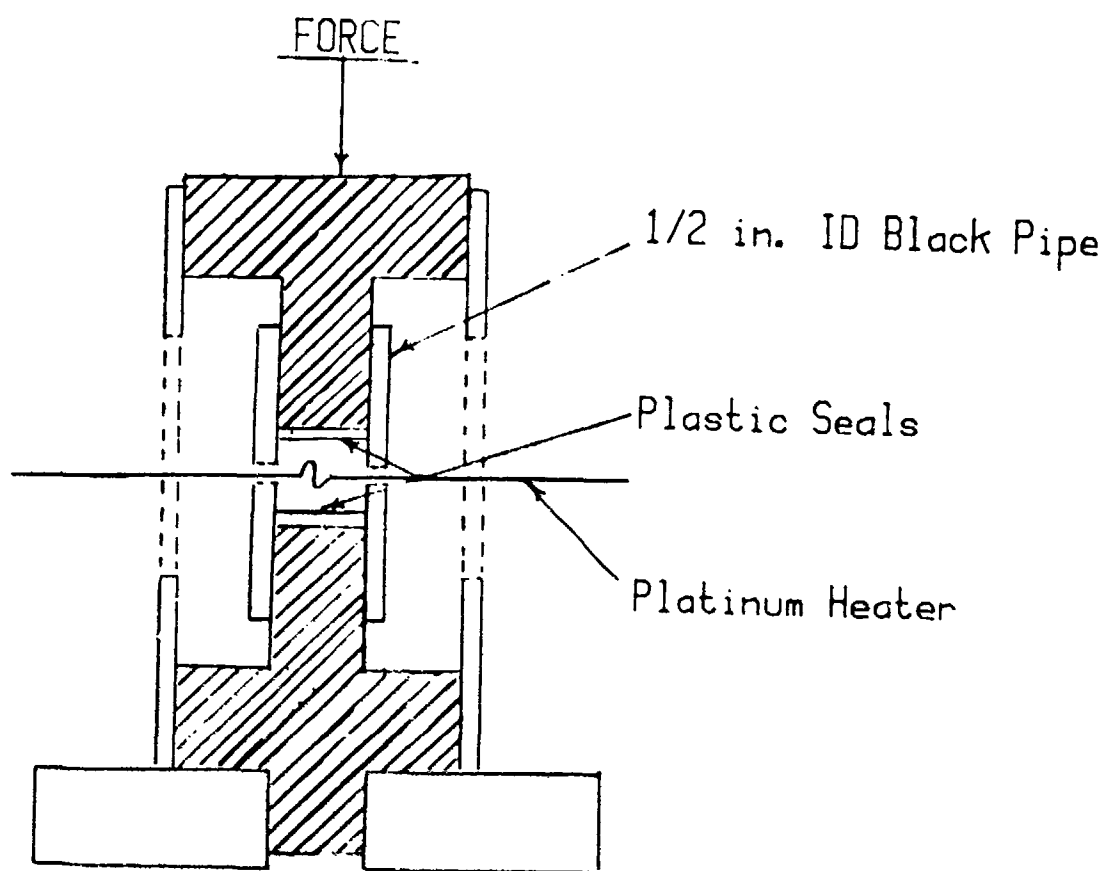


Figure 5. Ignition test fixture

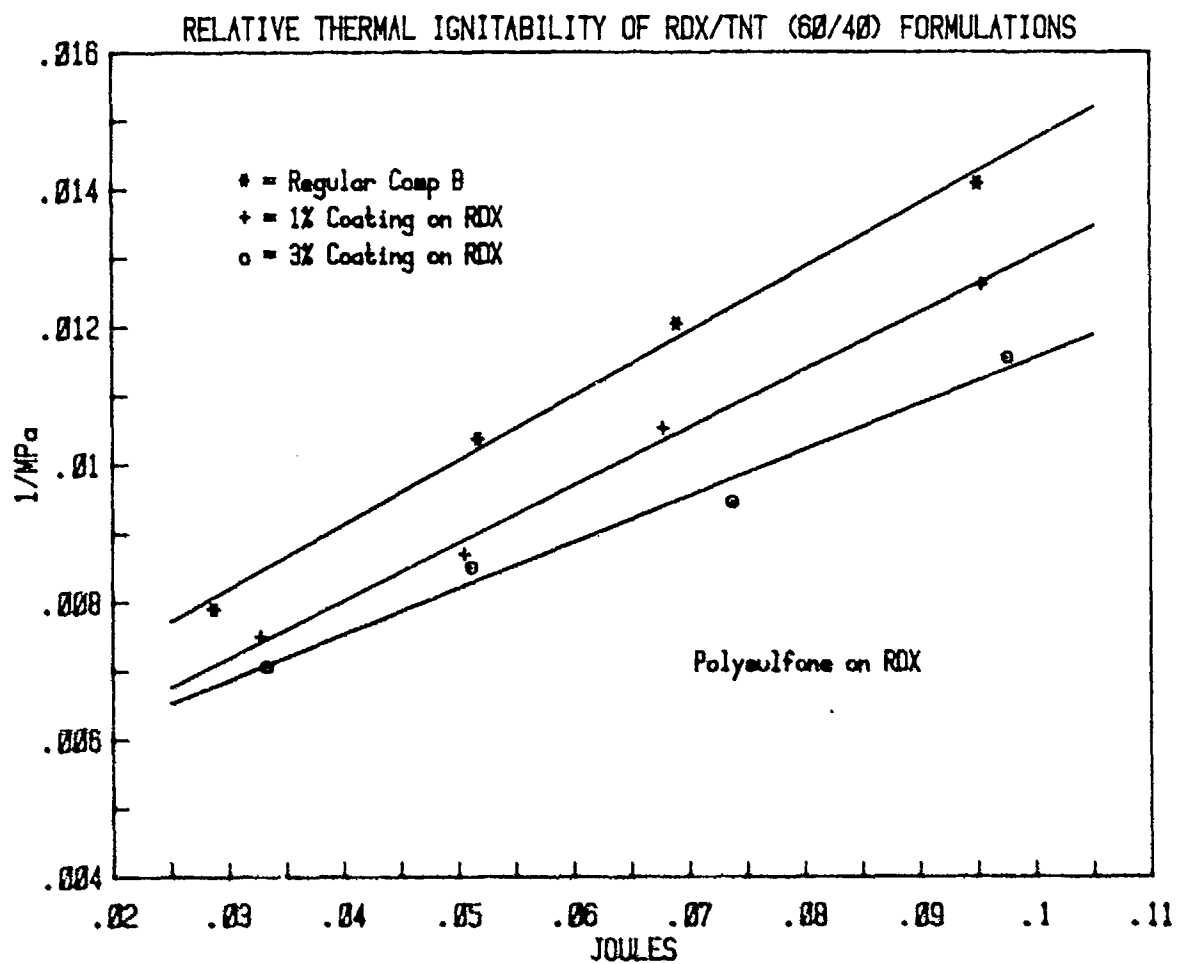


Figure 6. Effect of 1% and 3% RDX coatings

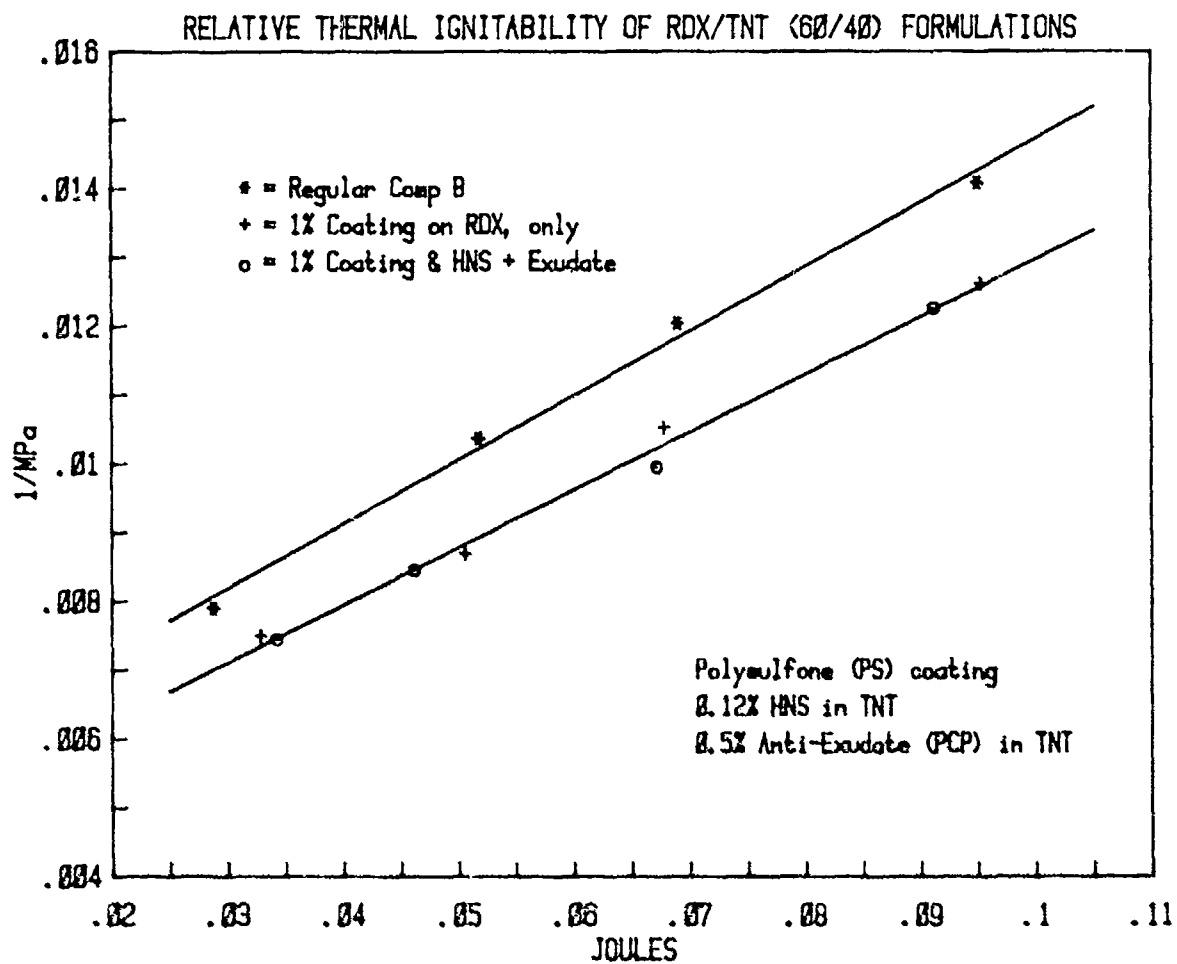


Figure 7. Effect of TNT modifiers with RDX coating

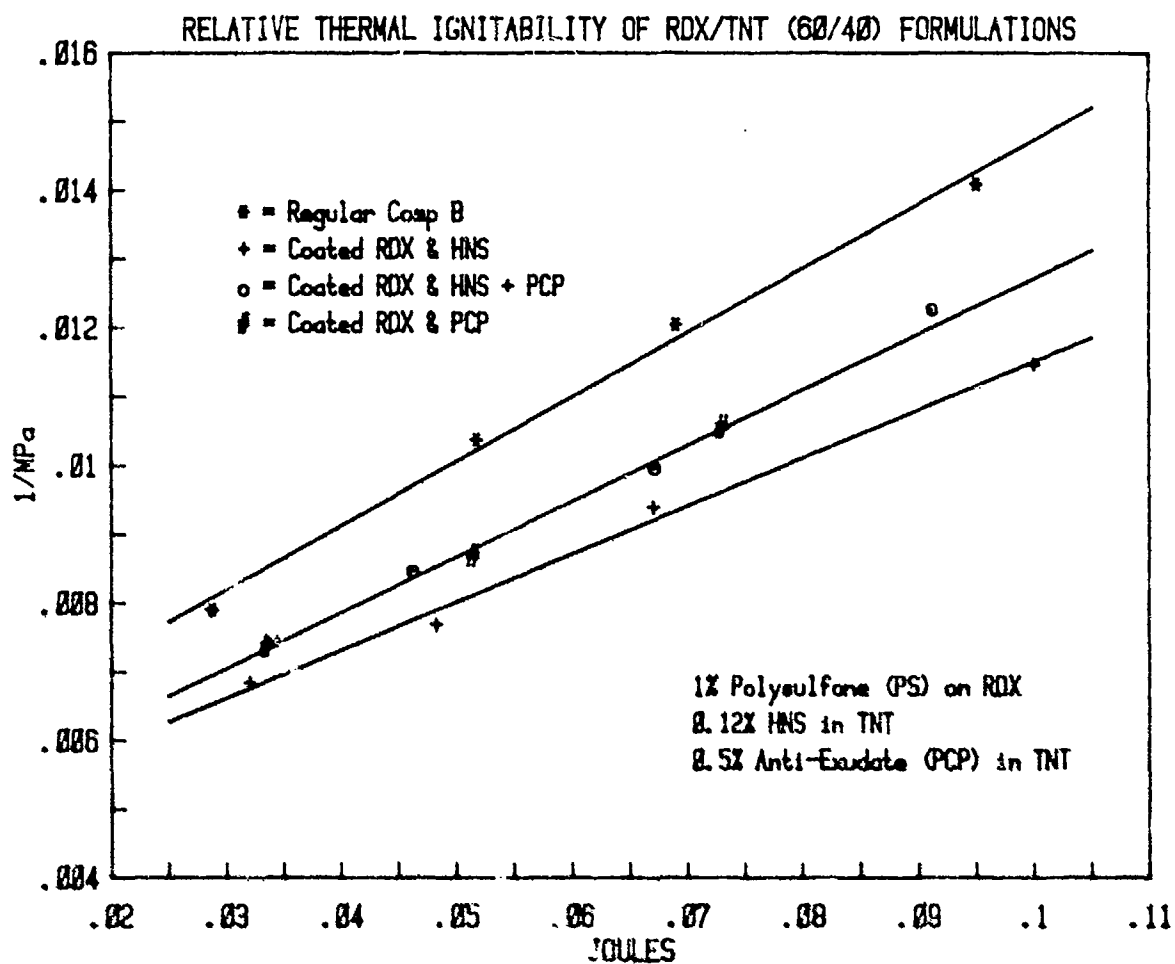


Figure 8. Effect of HNS without antitexudate (PCP)

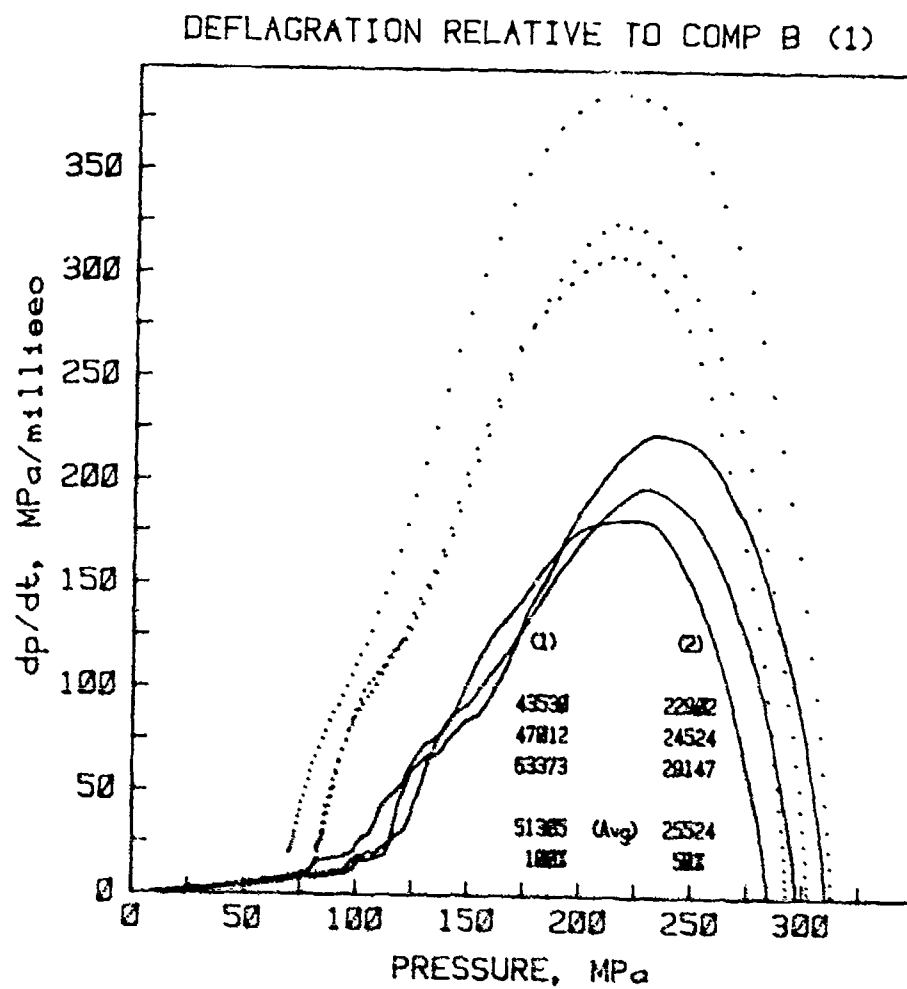


Figure 9a. 1% polysulfone coated on RDX (2)

DEFLAGRATION RELATIVE TO COMP B (1)

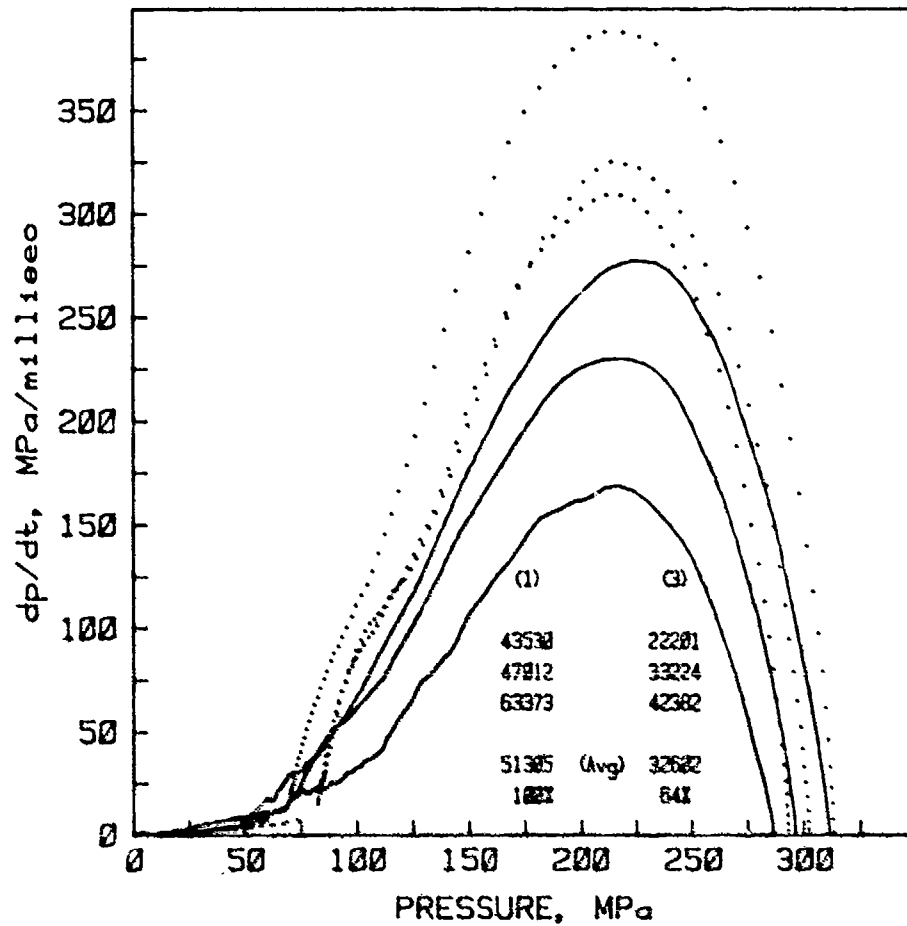


Figure 9b. 2% polysulfone coated on RDX (3)

DEFLAGRATION RELATIVE TO COMP B (1)

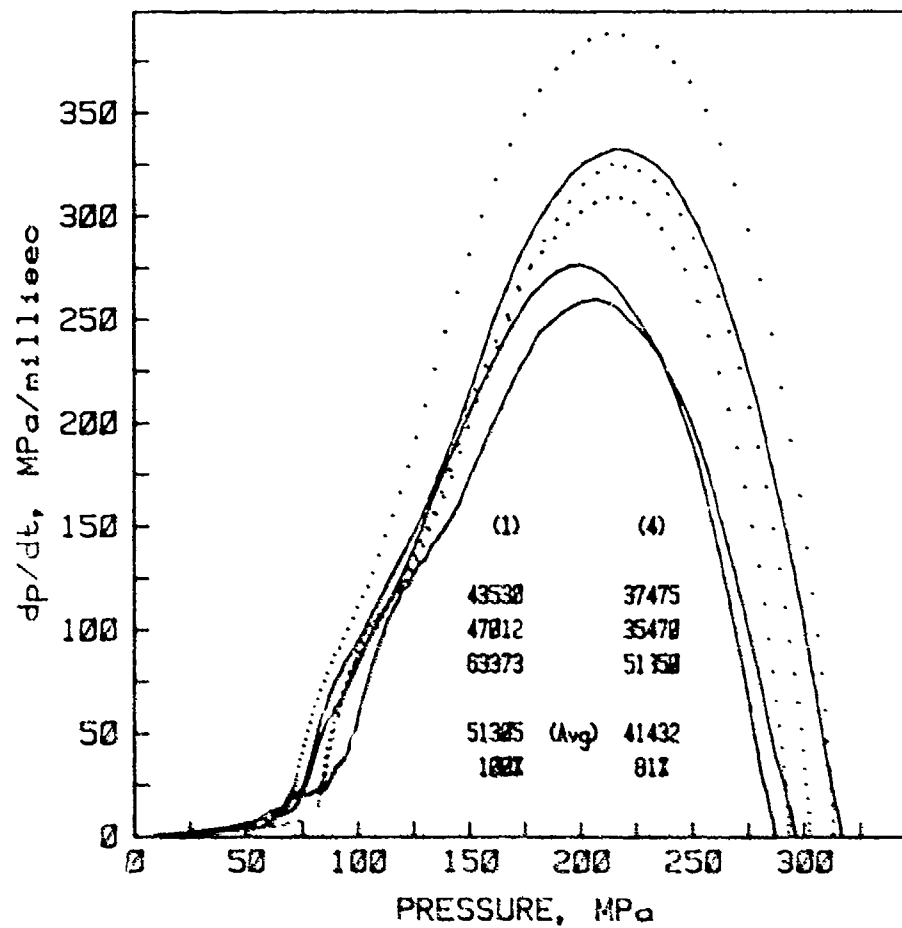


Figure 9c. 3% polysulfone coated on RDX (4)

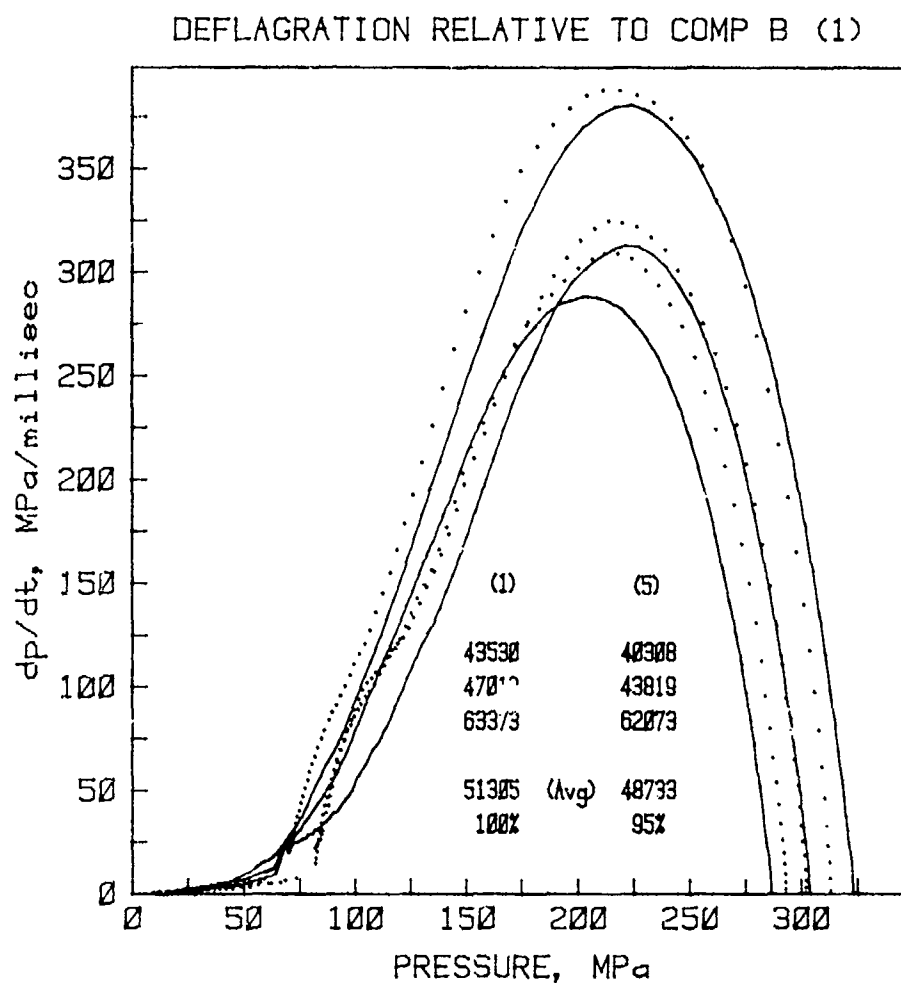


Figure 9d. 1% PS on RDX and 0.12% HNS in TNT (5)

DEFLAGRATION RELATIVE TO COMP B (1)

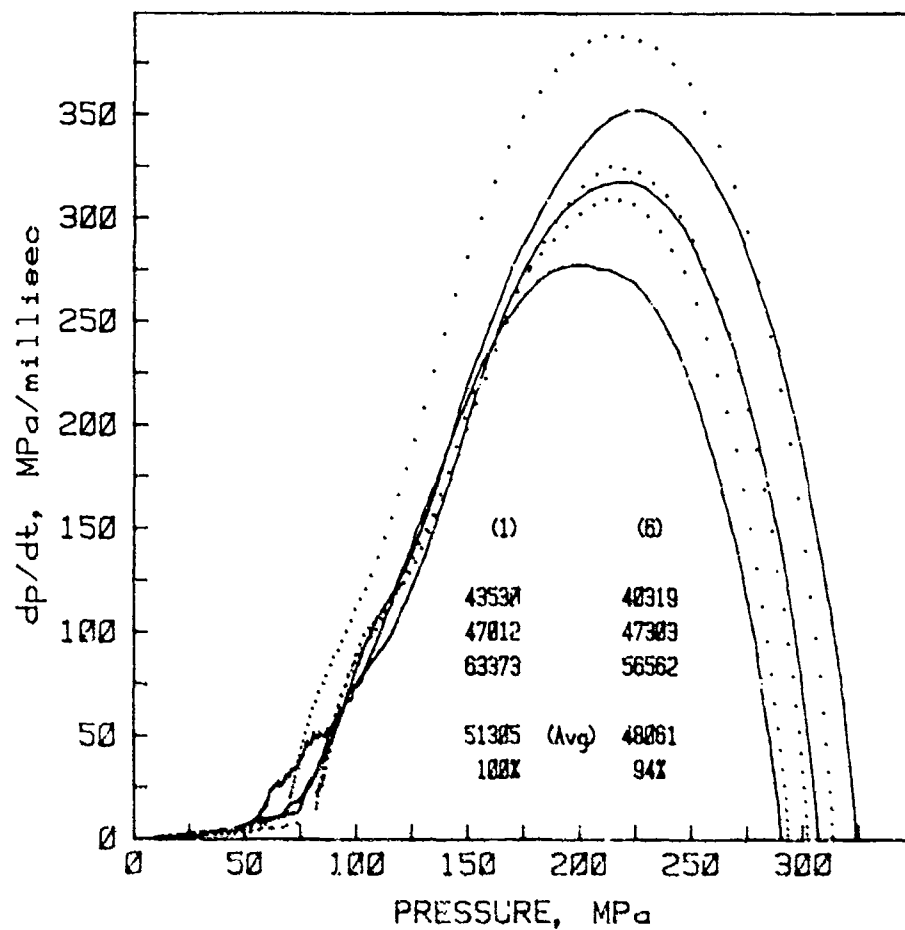


Figure 9e. 1% PS on RDX and 0.5% PCP in TNT (6)

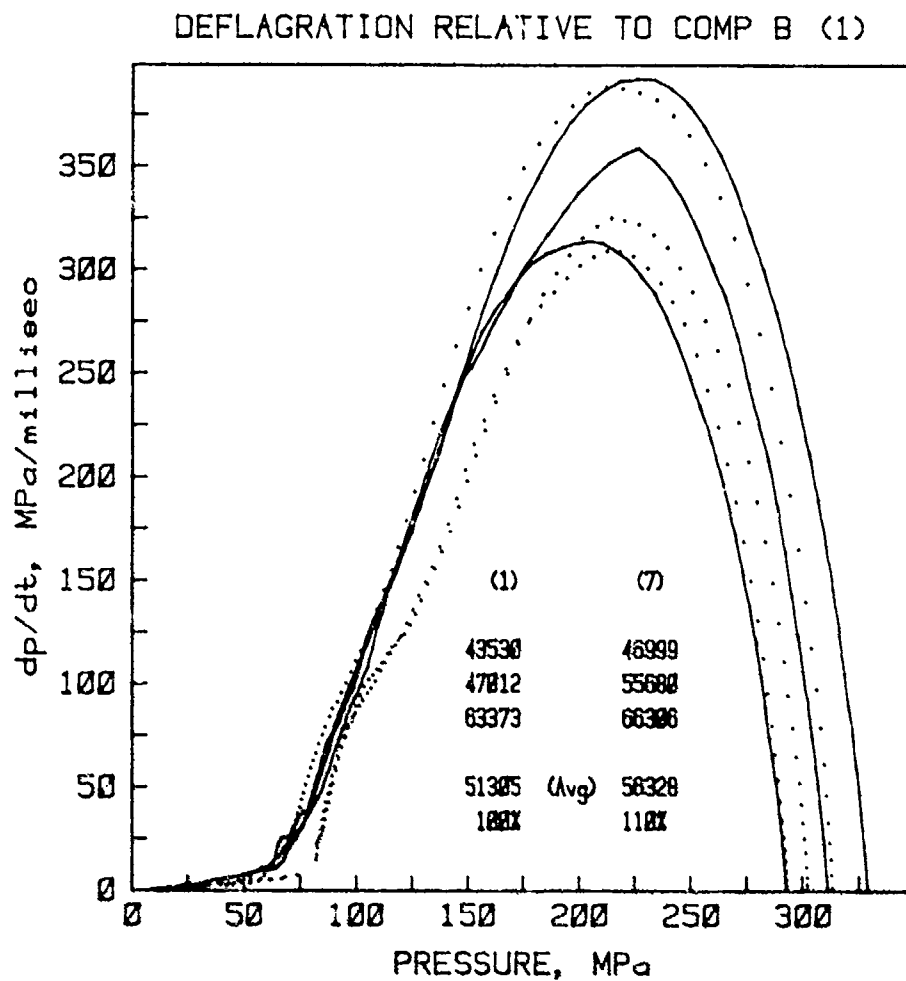


Figure 9f. 1% PS on RDX and 0.12% HNS + 0.5% PCP in TNT (7)

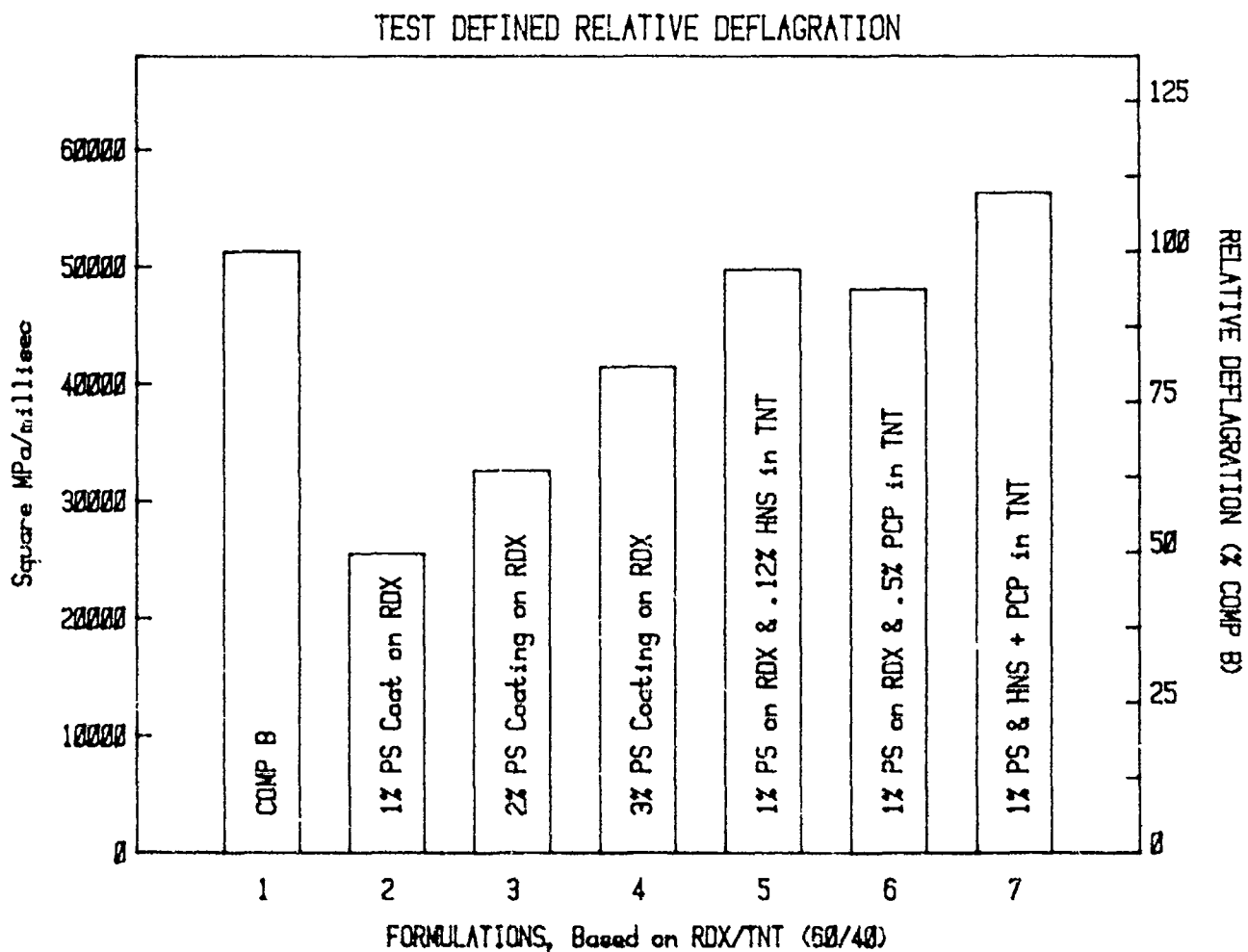


Figure 10. Summary of closed bomb burning test

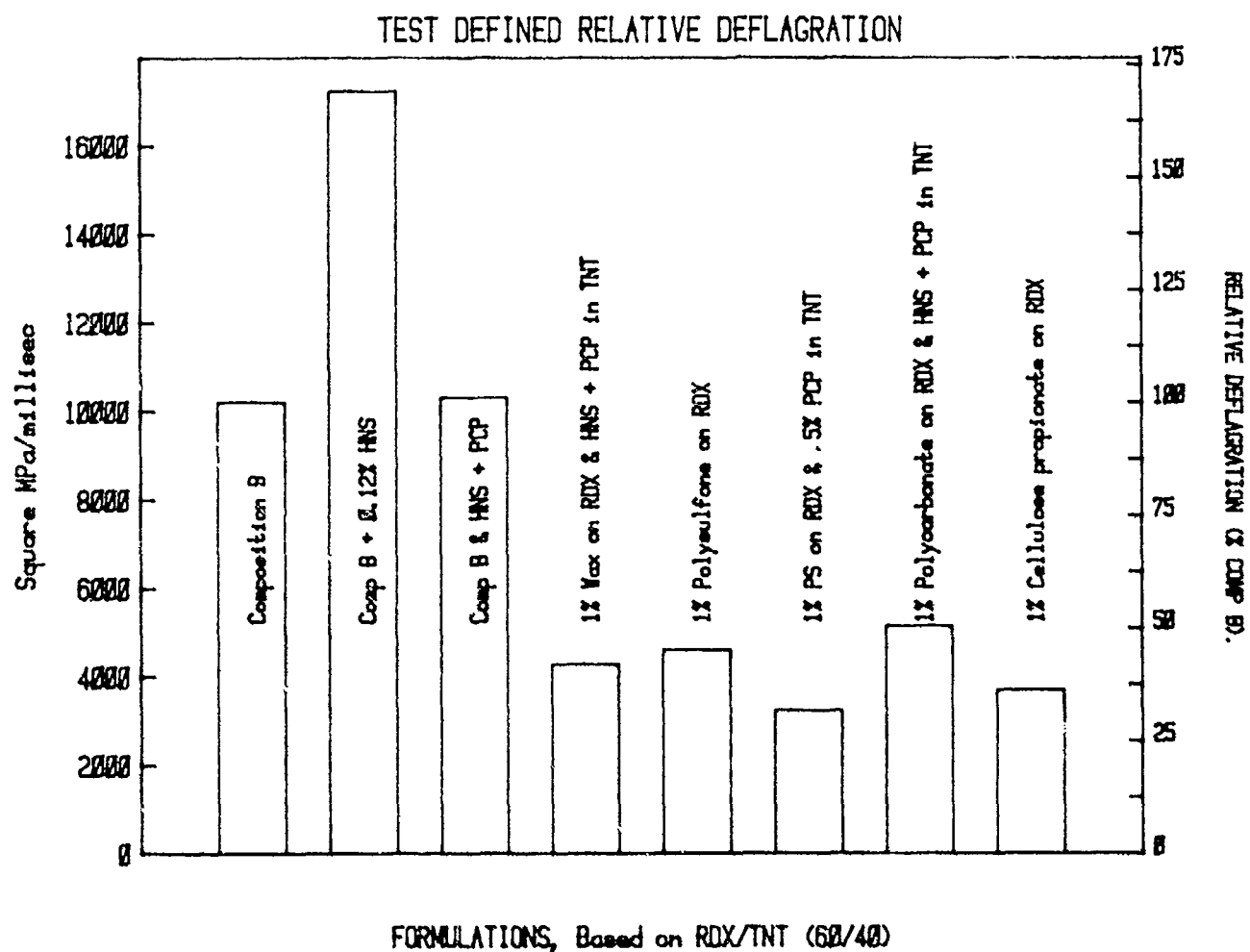


Figure 11. Previously reported data (ref 5)

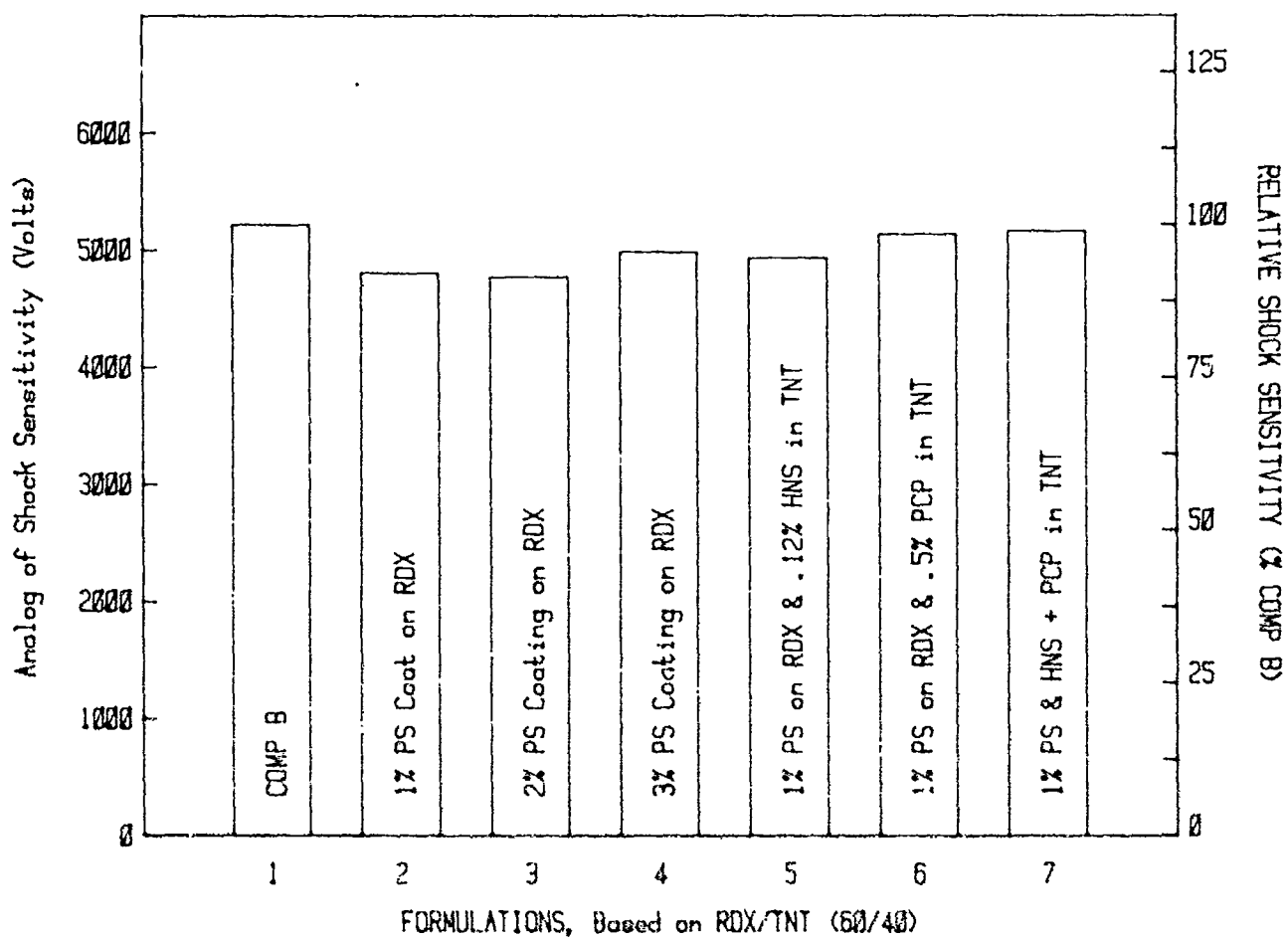


Figure 12. Summary of slapper stimulated shock sensitivity test

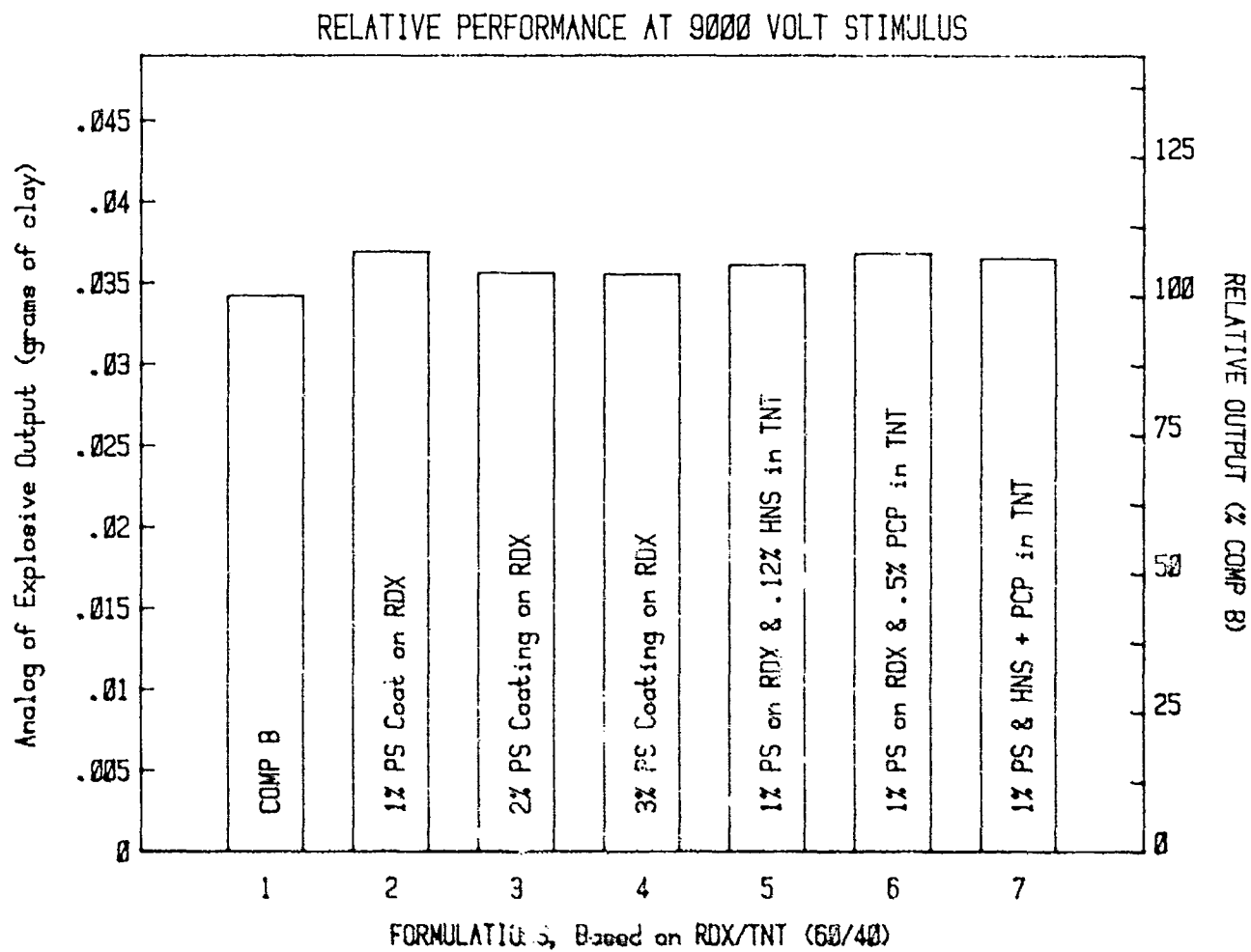


Figure 13. Summary of slapper stimulated explosive performance test

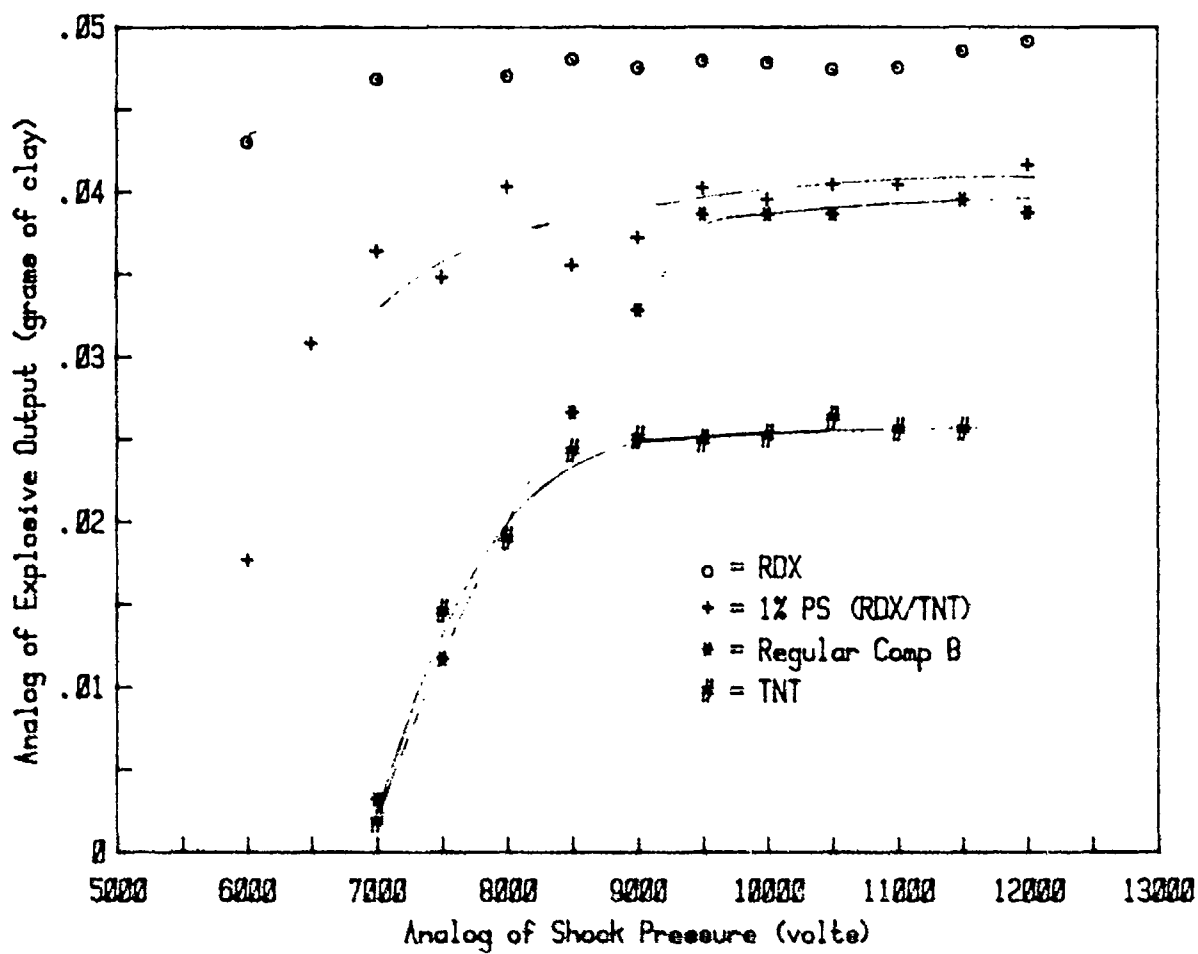


Figure 14. Performance of modified comp B versus standard explosives

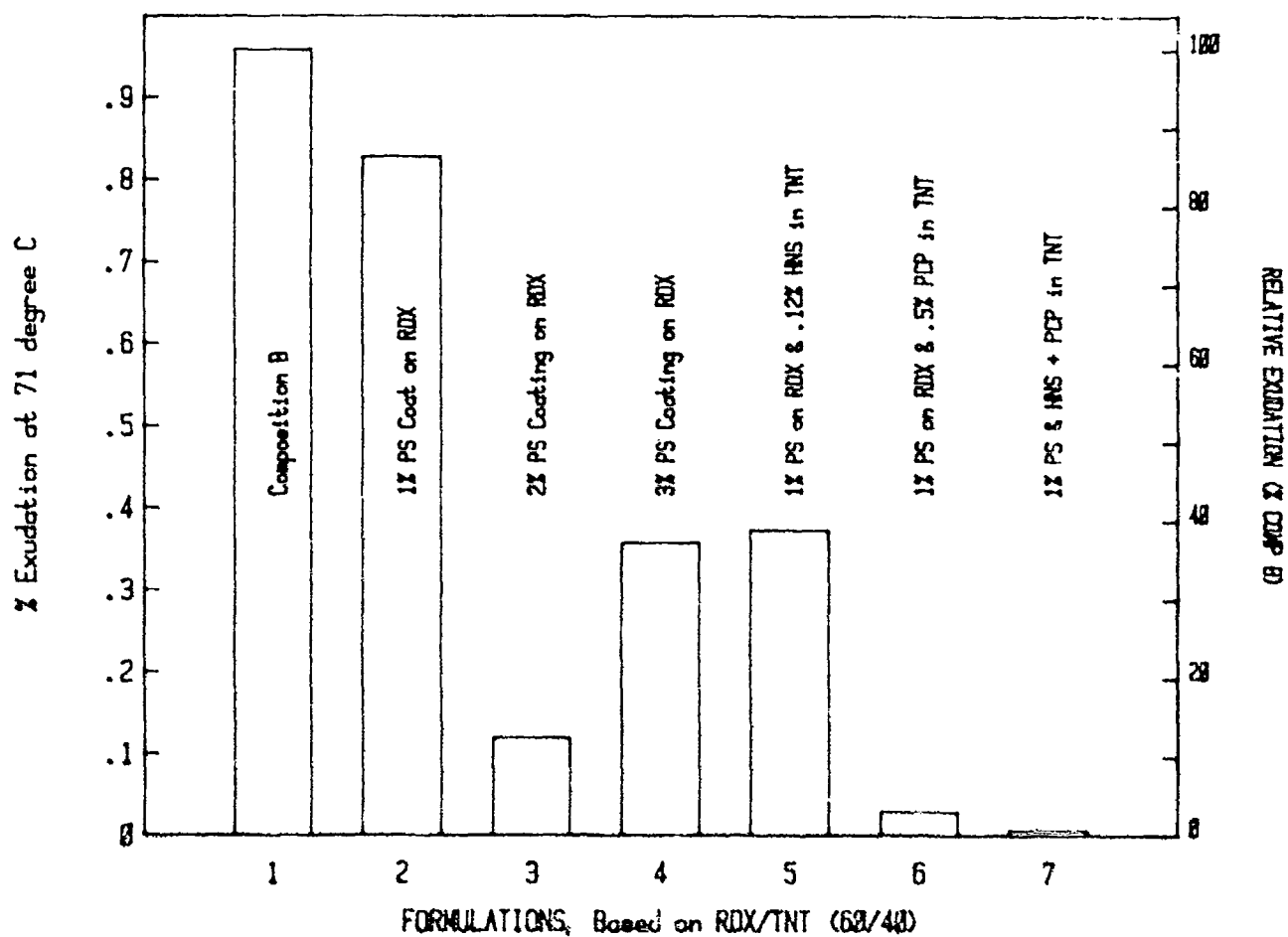


Figure 15. Summary of exudation test

REFERENCES

1. Starkenberg, J. J.; McFadden, D. L.; and Lyman, O. A., "Cavity Collapse Ignition of Composition B in the Launch Environment," Technical Report BRL-TR-2714, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, February 1986.
2. Akst, I., personal communication, P.O. Box 285, Pampa, TX, 79065, August 1986.
3. Seddon, K. C.; Ebenreuter, E. R.; and Connick, W., "The Growth of Explosion in Cast RDX/TNT: Closed Vessel Burning Studies of Differently Cast Specimens," Australian Defense Standard Laboratories Report 299, October 1967.
4. Parry, M. A. and Thorpe, B. N., "Influence of HNS on the Microstructure of Cast TNT," MRL-R-812, Materials Research Laboratory, Melbourne, Australia, April 1981.
5. Velicky, R. W.; Voigt, H. W.; and Voreck, W. E., "The Effect of Some Additives on the Closed Bomb Burning and Ignitability of RDX/TNT (60/40)," Journal of Energetic Materials, vol 3, pp 129-148, 1985.
6. Velicky, R. W. and Voigt, H. W., "The Effect of Additives on the Closed Bomb Burning of Cast RDX/TNT (60/40)," Technical Report ARLCD-TR-85013, ARDC, Dover, NJ, April 1985.
7. Velicky, R. W., "The Burning Behavior of TNT in the Closed Bomb," Journal of Energetic Materials, vol. 1, pp 177-205, 1983.
8. Velicky, R. W., "A Method to Evaluate the Burning Behavior of Secondary Explosives - Composition B," Technical Report ARLCD-TR-83030, ARADCOM, Dover, NJ, June 1983.
9. Machacek, O.; Marrello, M. L.; Eck, G. R.; and Velicky, R. W., "Effect of Chlorowaxes on Sensitivity of Comp B," ARDEC Contractor Report ARAED-CR-87015, ARDEC, Picatinny Arsenal, NJ, June 1987.
10. Velicky, R. W., "The Effect of Additives on the Ignition Parameters of RDX/TNT (60/40)," Technical Report ARAED-TR-86037, ARDEC, Picatinny Arsenal, NJ, October 1986.
11. Voreck, W. and Velicky, R. W., "Exploding Foil Shock Sensitivity Test," The Seventh Symposium (International) on Detonation, Annapolis, MD, July 1981.
12. Velicky, R. W., "A Laboratory Explosive Out-put Test Employing the Slapper Technique to Stimulate Detonation," Technical Report ARAED-TR-86036, ARDEC, Picatinny Arsenal, NJ, October 1986.

REFERENCES (cont)

13. Voigt, H. W., "Exudation Test for TNT Explosives Under Confinement: Exudation Control and Proposed Standards," Technical Report ARLCD-TR-83004, ARRADCOM, Dover, NJ, February 1983.

DISTRIBUTION LIST

Commander
Armament Research, Development and
Engineering Center
ATTN: SMCAR-IMI-I (5)
SMCAR-AEE (3)
SMCAR-AEE-WE (45)
Picatinny Arsenal, NJ 07806-5000

Commander
U.S. Army Armament, Munitions and
Chemical Command
ATTN: AMSMC-GCL
Picatinny Arsenal, NJ 07806-5000

Administrator
Defense Technical Information Center (12)
ATTN: Accessions Division
Cameron Station
Alexandria, VA 22304-6145

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSY-MP
Aberdeen Proving Ground, MD 21005-5066

Commander
Chemical Research, Development and
Engineering Center
U.S. Army Armament, Munitions and
Chemical Command
ATTN: SMCAR-MSI
Aberdeen Proving Ground, MD 21010-5423

Commander
Chemical Research, Development and
Engineering Center
U.S. Army Armament, Munitions and
Chemical Command
ATTN: SMCAR-RSP-A
Aberdeen Proving Ground, MD 21010-5423

Director
Ballistic Research Laboratory
ATTN: AMXBR-OD-ST
AMCBR-TBD, Philip M. Howe
AMCBR-TB-E, Robert B. Frey
SLCBR-TB-EE, Larry Vande Kieft
AMCBR-TB-EE, J. Starkenberg
Aberdeen Proving Ground, MD 21005-5066

Chief
Benete Weapons Laboratory, CCAC
Armament Research, Development and
Engineering Center
U.S. Army Armament, Munitions and
Chemical Command
ATTN: SMCAR-CCB-TL
Watervliet, NY 12189-5000

Commander
U.S. Army Armament, Munitions and
Chemical Command
ATTN: SMCAR-ESP-L
Rock Island, IL 61299-6000

Director
U.S. Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002

Commander
Naval Surface Weapons Center
ATTN: Code R12, S. Colley
Nesbit
H. Sandusky
P. Taylor
Code R121, M. Stosz
Code R122, L. Roslund
Technical Library
Silver Spring, MD 20902-5000

Commander
Naval Weapons Center
ATTN: Code 389, Thomas Boggs
Code 388, C. F. Price
Code 3835, K. J. Grahm
Code 3264, R. J. Cramer
Technical Library
China Lake, CA 93555

Center for Explosives Technology and Research
ATTN: Per-Anders Person
Andrew Block-Bolten
Taylor B. Joyner
Marc A. Meyers
Edward M. Roy
Technical Library
New Mexico Tech
Socorro, NM 87801

Sandia National Laboratories
ATTN: Div 2515, R. W. Bickes, Jr.
Technical Library
P.O. Box 5800
Albuquerque, NM 94550

Sandia National Laboratories
ATTN: Div 8357, R. W. Carling
C. F. Melius
P.O. Box 969
Livermore, CA 94550

Los Alamos National Laboratory
ATTN: CHM-1 MS G740, N. R. Greiner
MS P952, R. P. Engleke
M-8, MS J960, J. B. Ramsay
Technical Library
Los Alamos, NM 87545

Lawrence Livermore National Laboratory
ATTN: L-324, R. R. McGuire
L-368, E. L. Lee
M. Finger
L. Green
Technical Library
Livermore, CA 94550

Hercules, Inc.
Sunflower Army Ammunition Plant
ATTN: D. William Gearhart
Box 549
Desoto, KS 66018

Commander
Eglin Air Force Base
ATTN: AFATL-DLJE, Gary Parson
Eglin Air Force Base, FL 32542-5000

Joseph Hershkowitz
305 Passaic Avenue
West Cardwell, NJ 07006

Mr. Wallace E. Voreck, Jr.
44 E. Shore Trail
Sparta, NJ 07871

Irving B. Akst
Idos Corporation
1032 Duncan Street
Pama, TX 79065

Thermex Energy Corporation
13601 Preston Road, Suite 900W
ATTN: O. Machacek
Dallas, TX 75240

Commander
U. S. Army Armament, Munitions and
Chemical Command
ATTN: SMCAR-LEM, Bill Fortune
Rock Island, IL 61299-6000

Commander
Louisiana Army Ammunition Plant
ATTN: SMCLA-CO, LTC Gary F. Andrews
S. J. Shows
William Sanford
T. F. Davidson

P.O. Box 30058
Shreveport, LA 71130-5000